SOLID PLAN

EXPLORING INTEGRATION OF STRUCTURE AND SPACE IN MASS TIMBER BUILDINGS

A master's thesis by David Fjällström

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CHALMERS
UNIVERSITY OF TECHNOLOGY

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Master's thesis

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Master program: Architecture and Urban Design
Direction: Matter Space Structure

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ABSTRACT

Inspired by old log houses, this master's thesis explores the integration of load-bearing structure and space in modern, large-scale, mass timber buildings.

Relating to Le Corbusier's Dom-Ino system, in which the load-bearing structure is separated from the spatial organization, a contrasting approach is suggested:

The *solid plan*.

By using mass timber panels that have both load-bearing and enclosing qualities, the *solid plan* aims to dissolve the border between structure and space; to make them essentially the same.

The task taken on in the thesis is to design a load-bearing structure that by itself defines the spaces it holds, or seen from the other side, a spatial organization in which every element that defines the spaces is also part of the structure that holds them. One might call it building spaces.

Two rounds of explorations take place within a framework consisting of a predetermined building size and a set of rules.

The first one is about configurations of mass timber panels. Based on it, a first iteration of the design is made, accompanied by model photos acting as early visions of the spaces in it.

The second round of explorations is focused on the joints between the structural elements, treating them not only as structural details, but also architectural ones. Inspired by the way logs are interlocked in a log house as well as recent research regarding integral mechanical attachment, two joints are developed and implemented in a second iteration of the design. The structural principles are tested in a physical model and new photos are taken to capture the architectural expression of the joints.

By suggesting the *solid plan* approach for mass timber buildings and investigating how configurations and joints between elements can be solved, this thesis aims to contribute to the discussion about how we build with mass timber panels.

Keywords: wood, CLT, structure, space, joints

Me with an awesome bike on Orust

ABOUT THE AUTHOR

As I grow older, the essential things in life seem to crystallize. At this point, when I'm roughly 32 years in and the world is trembling from the impacts of human activity, I'm drawn towards simplicity and the appreciation of small things. This, a longing for simplicity and something that might be called gratefulness, has been an important emotional driving force in this work.

On a different note, I have always, since I was a kid, enjoyed figuring things out, working by hand and putting things together. It could be (and was) creating a kind of paper helmet with foldable paper binoculars, folding dinosaurs or making a parachute for my toy panda for it to use when jumping from the kite that I also made. Maybe one could say that I enjoy solving problems. This lust for figuring out solutions is deeply connected to a lust for understanding.

EDUCATION

Bachelor in Architecture at Chalmers University of Technology, 2013-2016

Master in Architecture at Chalmers University of Technology 2017-2019

PROFESSIONAL EXPERIENCE

Trainee at Liljewall arkitekter, 2016-2017

Trainee at Gothenburg City Planning Office in the Building Permit Department, summer 2018

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READING INSTRUCTIONS

DISCOURSE

This chapter introduces the thoughts behind this master's thesis and opens up the discussion to which it is a contribution.

AIM

Here, I state my vision and how I aim to contribute to the discussion opened up in the first chapter by asking three questions.

STRATEGY

In this chapter, the chosen approach is described and related to a reference. A framework for the explorations is then defined, followed by a description of the method used.

CONFIGURATIONAL EXPLORATIONS

This chapter contains the findings made during the first round of explorations regarding configurations of mass timber panel structures.

FIRST ITERATION

Here, a first iteration of the design is presented in a drawing, accompanied by model photos.

JOINT EXPLORATIONS

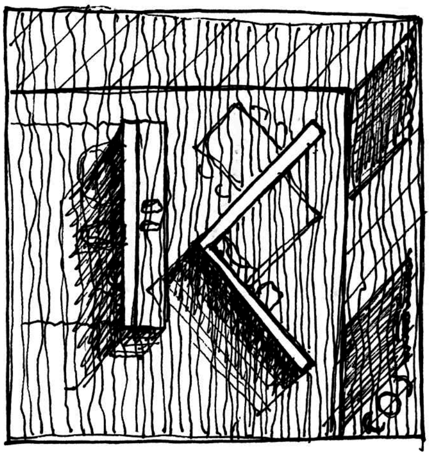
In this chapter, two prototypes of joints between mass timber panels are presented, followed by developed versions of these joints.

SECOND ITERATION

Here, drawings show how the joints presented in the previous chapter are implemented in the design.

CONCLUSION

In the final chapter, model photos of the second iteration of the design are used to answer the questions raised in the second chapter.



Sketch of a home with a *solid plan*

CONTENTS

Log houses in Vormsele

A BRIEF HISTORY

Building with wood is part of our history. Its availability and low cost, as well as the fact that it kind of manufactures itself, has made it a go-to material for buildings, furniture and tools through all time. New tools and techniques have been developed, creating new possibilities to re-shape and assemble wood. But there is a gap in this development. During roughly a hundred years, from the end of the 19th century until 1994, there was a national restriction against wooden buildings taller than two stories. The main reason for this was the risk of fire in cities (Falk, 2005, pp. 27-31).

During this time, a lot happened in the field of large-scale construction. And because of the restriction against tall wooden buildings, this development happened mostly around steel and concrete. At the moment, these two materials dominate in large-scale construction. Normally, they make up a load-bearing structure that is then accompanied by many other materials. Together they make up the layered architecture of today.

In 1994, the fire regulations changed from being material-based to performance-based. This opened up for the use of wood in buildings taller than two stories as long as they met the demands regarding fire safety. Today, mass timber is gaining ground in large scale construction, but in an industry that has gotten used to a layered architecture where the load-bearing structure is often separated from the spatial organization, it is often introduced as a load-bearing material, while its atmospheric quality is neglected.

I argue that a shift of mindset is needed when designing mass timber buildings, from one where the load-bearing structure and the spatial organization are two separate systems, to a holistic one where they are integrated and depend on one another. This way, a new kind of mass timber architecture is possible; one where the structural elements are present in the spaces, and the joints between them are visible and comprehensible to its inhabitants, much like in the log houses seen in the image.

Solid timber wall in Pulpit Rock Mountain Lodge by Helen & Hard (author's own photo)

SENSORY (IN)CONSISTENCY

In the philosophical theory of phenomenology, the bodily experience is considered to be our most truthful way of getting to know the world, as opposed to science where theoretical knowledge and understanding is elevated above all else.

The French philosopher Maurice Merleau-Ponty (2008, pp. 45-46) explains the difference between the two approaches very clearly with an example about a lemon. First, he describes the lemon in a scientific way by listing its different measurable qualities; its shape, its colour, its feel and its taste. He then argues for the insufficiency of this description, claiming that it doesn't capture the unity of the lemon, but separates it into a set of qualities, independent from each other.

As I understand Merleau-Ponty, the misconception, subtle, but very important, lies in where and when the lemon is considered to be a unified object.

In the scientific world, the qualities of the lemon are assembled in our heads, from completely separate data. We receive the data describing it, and in our rational minds we assemble it to be a lemon. A lemon like this would be relatively easy to reproduce. In a phenomenological world, on the other hand, the lemon is always a unified object. The different sensory input we get from it are nothing but different manifestations of one and the same lemon; we <u>experience</u> it, and the more the sensory input, the stronger the experience.

Now, with this example in mind, let's consider a composite assembly, like for example a gypsum-clad wood-frame wall. Its appearance and feel comes from the gypsum (or whatever paint or wallpaper is put on it). Its ability to carry loads, however, comes from the wood that is hidden inside. Additionally, the sound you hear when you knock on the wall is some kind of composite sound stemming from both the gypsum and the wood. The sensory output of the wall is not unified, but just as composite as the wall itself.

Photo of layered structure (author's own photo)

ON LAYERED ARCHITECTURE

As touched upon earlier, the architecture of today is a layered one. In it, different parts fill different needs and are assembled into composite structures. Even though this makes sense as a way of making sure a building meets certain requirements, it seems to me as if the separation we have made between different disciplines and theoretical fields has found its way out in the build reality.

I argue that the logic of the layered architecture is not useful when building with solid materials. Let us go back to the example about the lemon mentioned in the section called *sensory (in)consistency*. And instead of a lemon, let us consider a solid brick wall. It has measurable qualities, like its thickness, the amount of load it can carry, the texture of the bricks and so on. Let us now consider a composite wall that resembles all of these qualities. Here, a load-bearing timber frame carries the load, whereas a thin layer of brick tiles mounted on a thin board provides the texture and feel of the bricks and so on. Even if this wall manages to resemble all the measurable qualities of the brick wall, the only actual brick wall will be the imaginary one in my head. Different sensory input will be given by its different parts, and the formation of the brick wall will happen in the human brain. It is like the measuring procedure, but reversed, and instead of measuring the qualities of the solid brick wall, the results of a previous measuring are projected back into the physical reality, not without a loss of richness.

I would also like to raise another critique on the layered architecture, namely that it is limiting materials to be used for only one or a few of their qualities, rather than being fully utilized. Is it not true that wood not only has a load-bearing quality, but also has a visual one, and a tactile one and so on? Why then hide it? Is it not a waste of potential?

To conclude, the logics of layered and solid architecture are fundamentally different and incompatible with each other and should be applied thereafter.

Log house in Vormsele

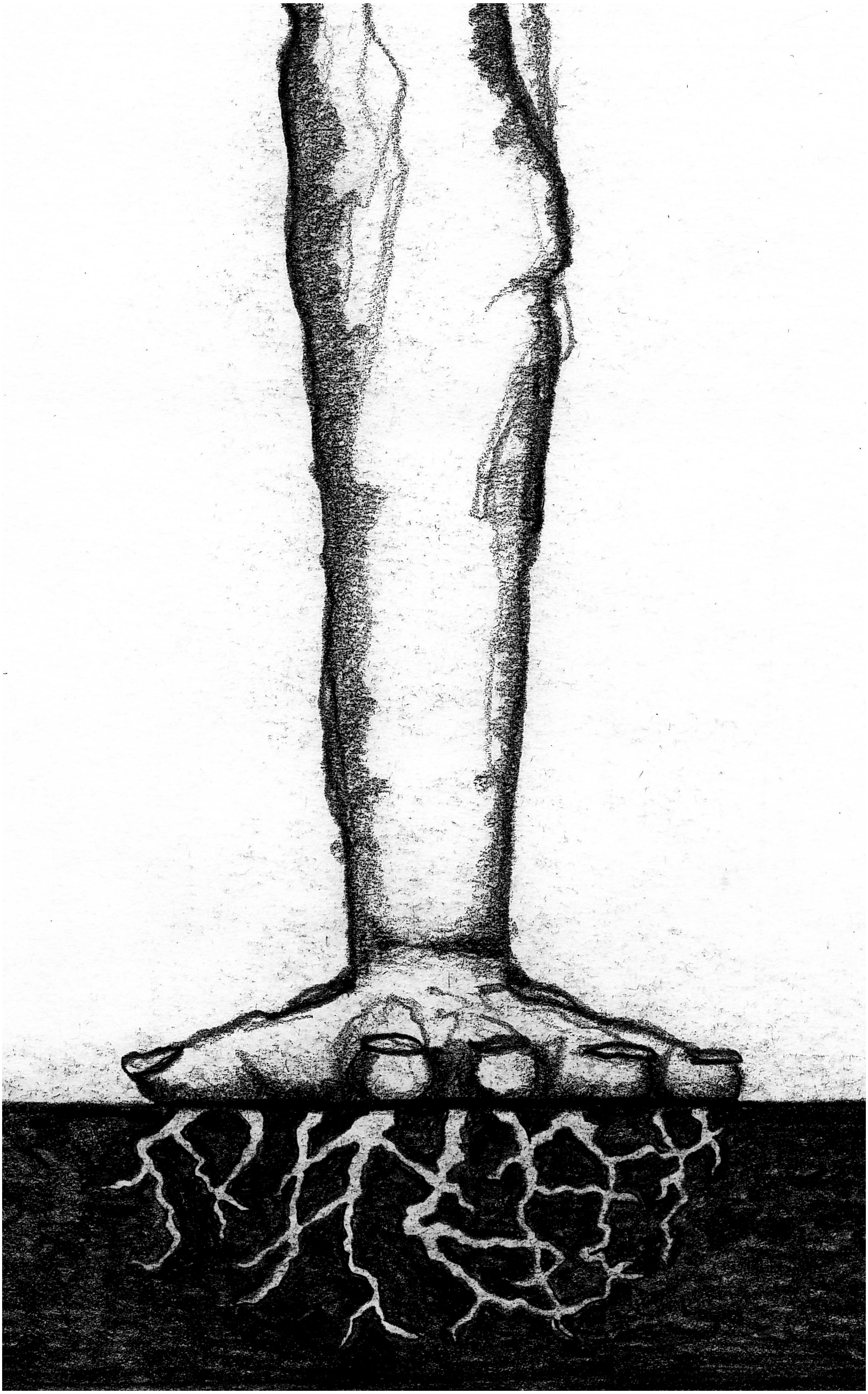
ON SOLID ARCHITECTURE

By solid architecture I mean the kind that is built from what you see, and that gets its shape from the possibilities and limitations of that which it is built of.

One example is the brick vault. It is an opening that can serve a spatial purpose, but at the same time it is part of the load-bearing structure of the building. It cannot have just any shape, but gets its shape from the logic of how loads are transferred in compression. The brick vault is spatial AND structural.

Another example is the log house. Its spatial division is made by placing logs on top of each other and interlocking them where they intersect to achieve stability. By following this logic certain forms can be achieved, while others cannot. Thus, the spatial qualities are connected to the structural ones, and vice versa.

What separates these two examples from most contemporary buildings is that the design is, by its nature, both structural and spatial at the same time. Another difference lies in the role of the structural joints. In the solid examples, they are also architectural details, whereas in contemporary architecture, they are often hidden, while the architectural detailing is (not always, but often) made in the outermost layers of layered structures.



Drawing of human roots

VISION

A few years ago, when writing an essay in school, I got familiar with the philosophical theory of phenomenology. I think it was then that I realized that everything I know about the world, I have learned through my senses.

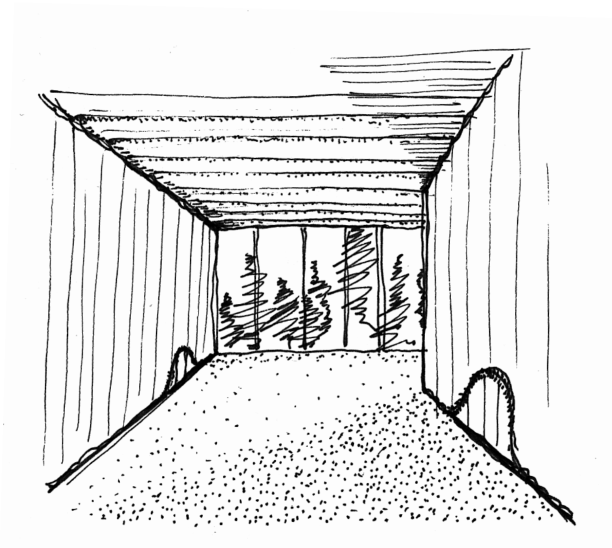
My body is the interface between my consciousness and the world. It is the only channel through which I am reachable. That is why the smell of autumn is not just a smell, or the fabric of my shirt is not just a fabric, or why a hug is not just a hug; they are my roots, stretching out into the world, connecting me to it. Cut them off and I will know nothing.

Could it be that our roots go only as deep as our senses can reach, and that a wallpaper provides only about a millimetre of soil for them to penetrate, whereas a log provides several decimetres? And could it be that we, similar to the electrons running in a copper wire inside an electric cord, can become isolated and kept inside, only by a thin layer of plastic?

I believe that being inside of an incomprehensible home, one that I cannot understand, one that hides parts of itself from me, limits the depth of the soil into which my roots go, and makes me feel detached. A home like this is designed for (and by) the mind, not for the body.

Merleau-Ponty (2004, p. 48) states that people's characteristics and worldview are revealed by the things they choose to surround themselves with. In society today, however, many of the things I surround myself with are given to (or bought by) me. Their origin, as well as the ideals they represent, are often out of my control. This also applies to the home, where there is a wide range of claddings and floorings, all bearing within themselves some kind of meaning. Constantly surrounded by them, I am left to either accept what they impose on me or live in constant dissonance with my near surrounding. I long for a home stripped of these imposing artefacts.

My vision is a new way of building with wood, one that allows my roots to go deep, one that I can sense and understand, one that gives me a unified and rich sensory input.



Sketch from process

CONTRIBUTION

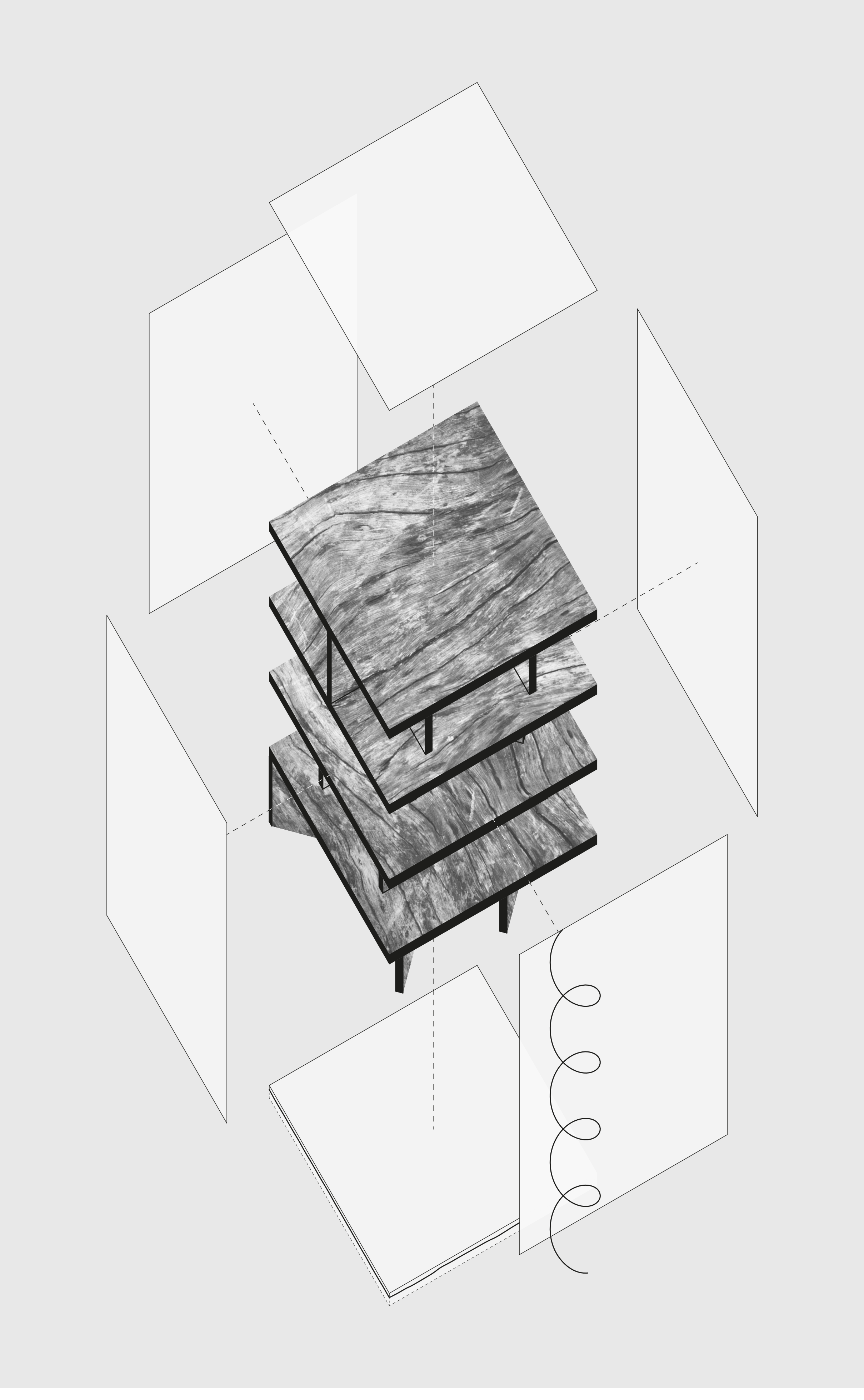
The development of mass timber panels is ongoing and large-scale wood construction gets less and less controversial as the number of realized projects grow. Where I see potential is in the configuration of the elements and in the joints. Mass timber panels have a structural potential that rarely is fully utilized and it is more or less standard to use steel connectors and screws to put them together, even though wood is capable of transferring loads directly between pieces in wood to wood joints. Surely the conventional configurations and joints are sufficient from a structural point of view, but i believe that there is a potential in developing the spaces defined by mass timber panel structures.

Based on these reflections, I can frame a field of exploration through asking the following questions:

How can mass timber panels be configured into multi-storey structures, and what spaces can they define?

How can joints between mass timber panels be designed to be not only structural details, but also architectural details?

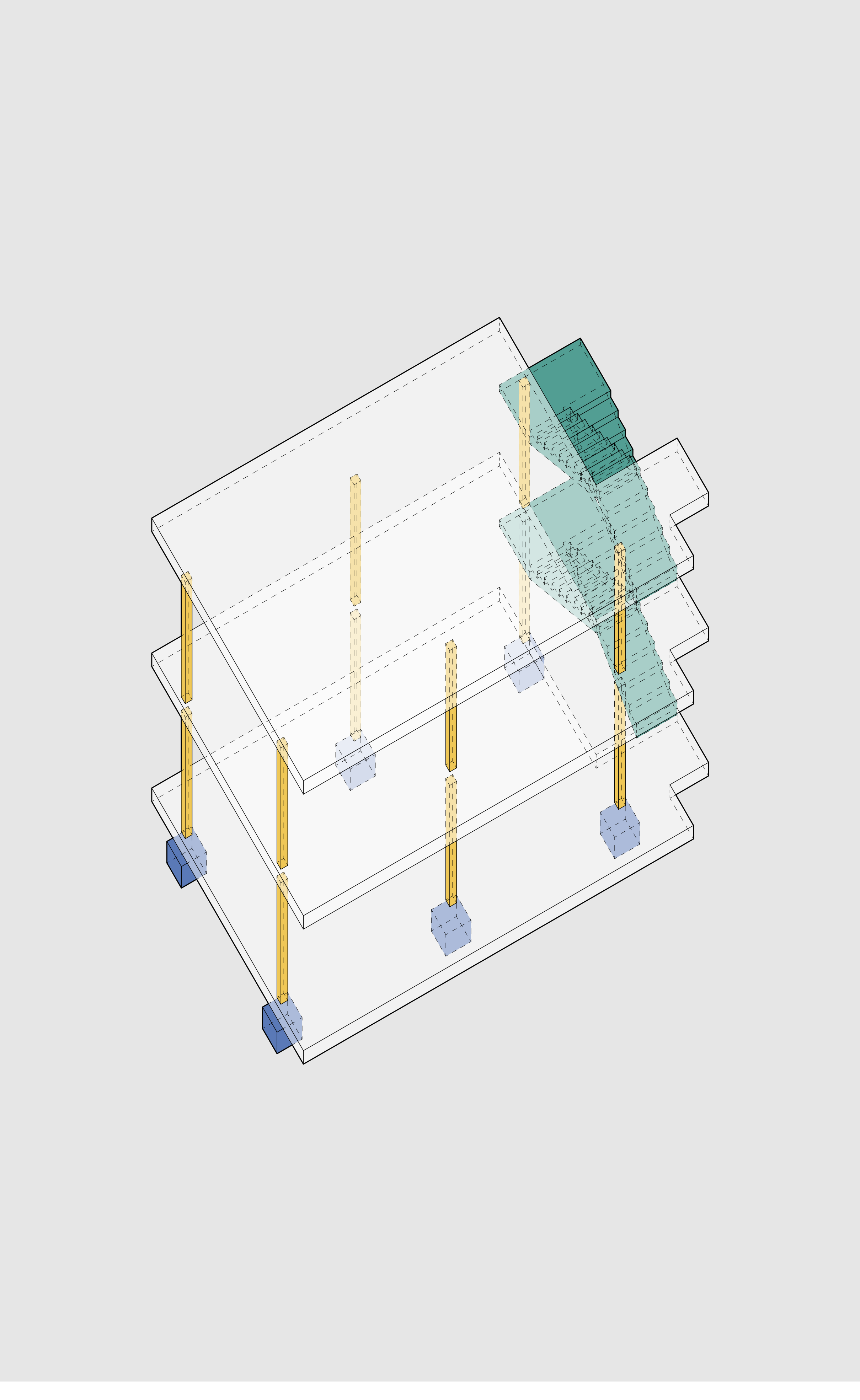
How can form be used to transfer loads between elements, and how can this transferring of loads manifest itself in the spaces defined by the structure?



Conceptual drawing

THE *SOLID PLAN* APPROACH

When designing a building where every wall is load-bearing, a problem arises. The need for spatial divisions is often bigger than the need for load-bearing walls. Therefore, I suggest placing all the load-bearing walls inside the floor plan, leaving the facade free. This approach can be compared to Le Corbusier's Dom-Ino system, but instead of a free plan, it features a *solid plan*. This way the load-bearing walls can be used to define different spaces, while the purpose of the facade becomes solely to be a border between inside and outside. One could say that the main idea behind Le Corbusier's system is a total <u>separation</u> between the load-bearing structure and the spatial organization, whereas in the *solid plan* approach, the main idea is a total <u>integration</u> of the two.



Axonometric drawing of Le Corbusier’s Dom-Ino system

RELATING TO THE FIVE POINTS

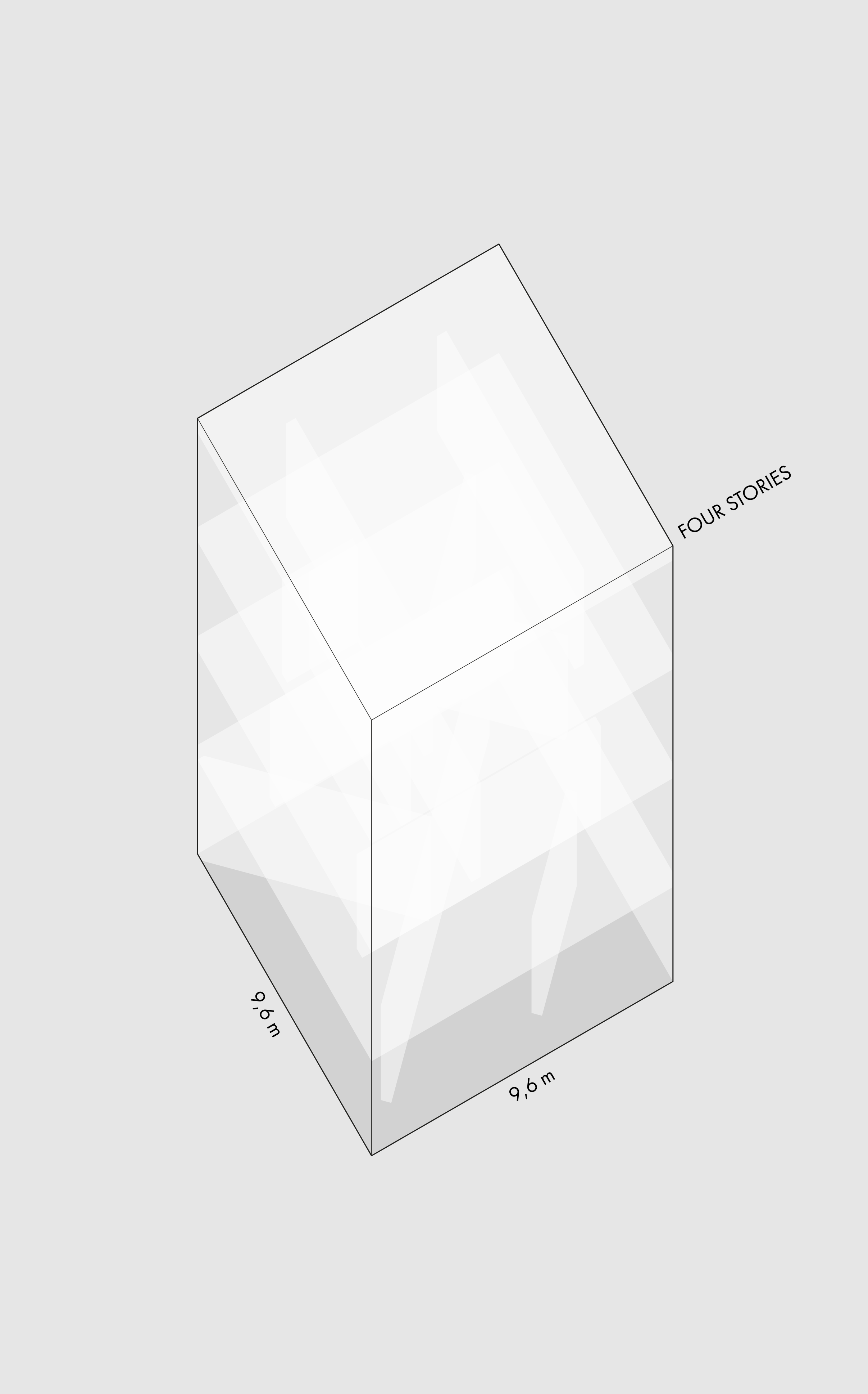
In the 1920's, Le Corbusier established his five points for a new architecture. Considering that he was part of forming the principles of modernism, which in turn was the base of much of the industrially built architecture of the second half of the 19th century, and that traces of these principles are still to be found even in contemporary architecture, I argue for their relevance. In addition to that, the aim of this master's thesis is of a similar nature as that of the Dom-Ino system (a structural principle published by Le Corbusier in 1914); it is about proposing *a new way of building* (von Moos, 1979). Therefore, I have taken the liberty of relating to the five points:

1. Pilotis: Though possible, I would (loosely) argue that this point is somewhat outdated. Nevertheless, there is a need to separate the wooden structure from the moist ground.

2. The roof garden: I am with Le Corbusier on this one, I really appreciate roof gardens. But, since I am working with the integration of structure and space, I will take the opportunity to mention an idea that I have, but that I did not develop much in this work. When building with mass timber, it is not unusual to add something heavy on top of the building to weigh it down. Normally, concrete would be used for this, but what if it could be a heavy roof garden instead? Maybe all the soil taken out of the ground when making the foundation could be stored near the site during the construction of the building and then be placed on top of it?

3. The free plan: Even though I am proposing a *solid plan* in which every wall is load-bearing, one could argue that it is indeed free, since all floor plans can be designed differently. Also, I argue that the free plan suggested by Le Corbusier is not really free, since columns also have a spatial quality.

4-5. The elongated window and the free facade: Both these points are fully compatible with the structural principle proposed in this thesis.



Predetermined building size

FRAMEWORK DEFINITION

In a recorded lecture at Harvard Graduate School of Design, Christian Kerez uses the rules of a game as a metaphor for the inner logic of a project, that which gives it its shape. Early on, he proclaims his fascination for rules and their usefulness in everyday situations: "[...] I like a lot to look at whatever I do in terms of inventing rules and in this sense also consider everything I do as a project" (Harvard Graduate School of Design, 2012).

By paying attention to the rules of a game, rather than the outcome, meaning is given to the logic that creates form. One could almost say that the real design task in such a project is designing the rules. The project could then be seen as a physical manifestation of those rules.

The rules of my game, if I may borrow Kerez's metaphor, are the following:

- The structure must be four stories high.

  Reason: To work at a scale that is relevant today and that is too big for traditional log construction.

- Every element in the structure must be part of the load-bearing structure.

  Reason: To isolate the integration between structure and space.

- Every floor must have three walls.

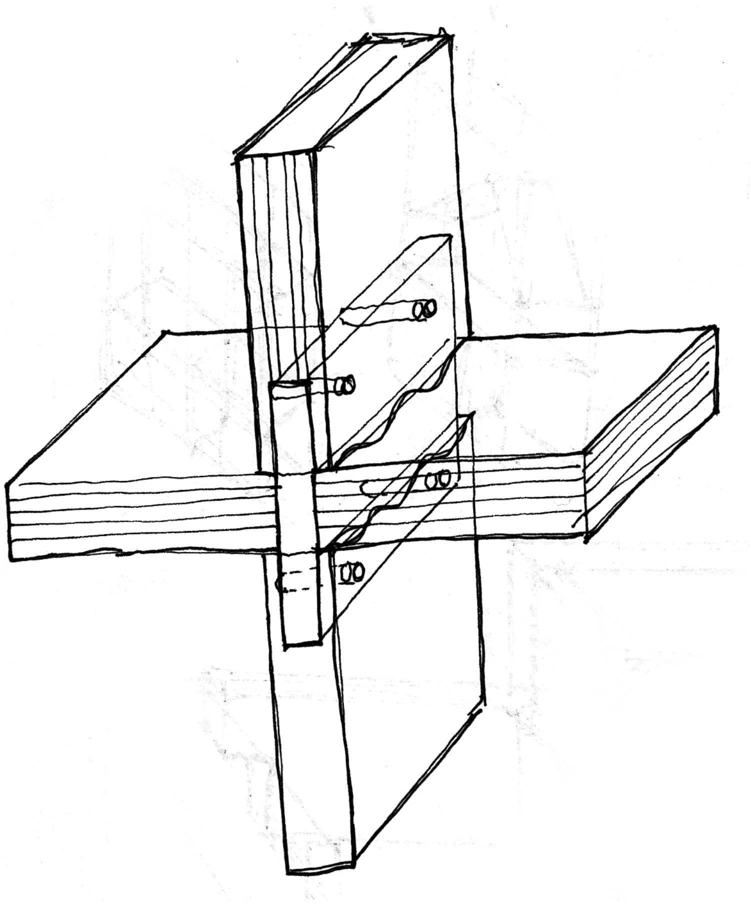
  Reason: This is the minimum to achieve horizontal stability.

- Every floor plan must be different.

  Reason: To explore the possibilities to use the structure to define different spaces.

- The facade must be free.

  Reason: To use the load-bearing elements to divide the interior space rather than to separate the interior from the exterior.



Sketch from process

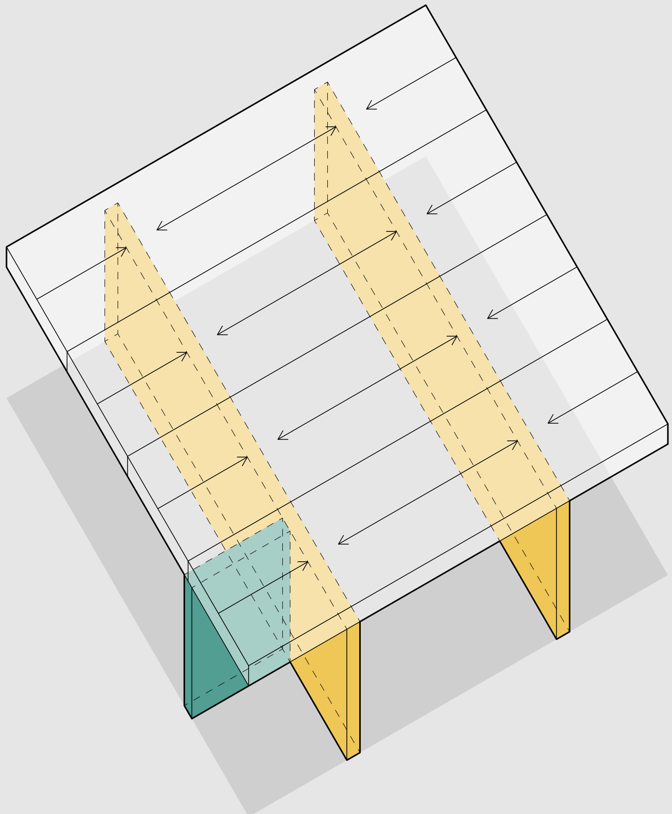
METHOD

The main tools used in this thesis are hand sketches, model building, model photos, 3D-modeling and refined drawings. The ideas presented have been developed in an iterative process with recurring presentations to my examiner, the team of tutors and my studio colleagues, followed by feedback.

Below is an attempt to describe the typical workflow:

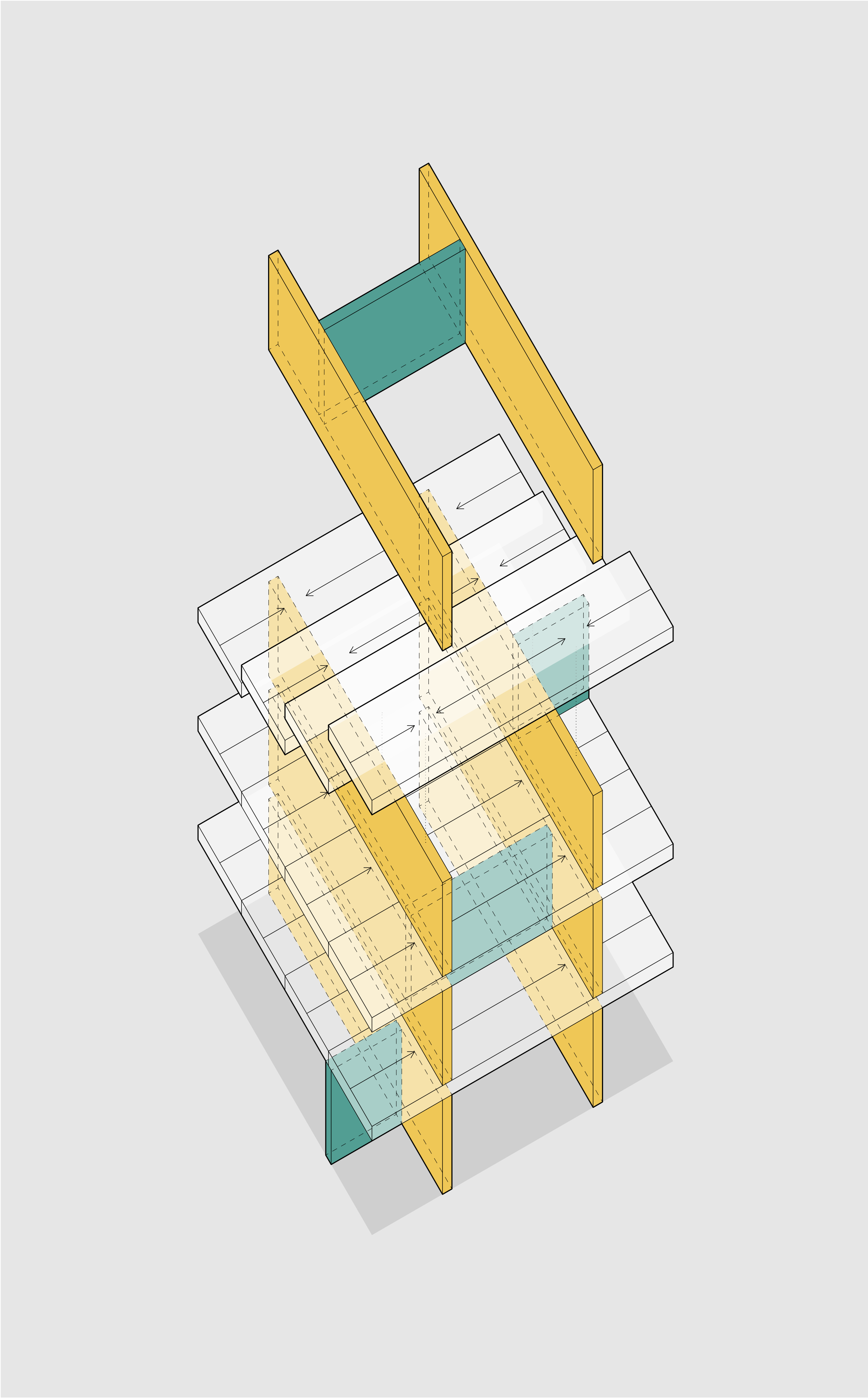
1. Idea
2. Hand sketches
3. Physical model building
4. Model photos
5. 3D-modeling
6. Refined drawing
7. Presentation
8. Feedback
9. Refined idea

Repeat steps 2-9.



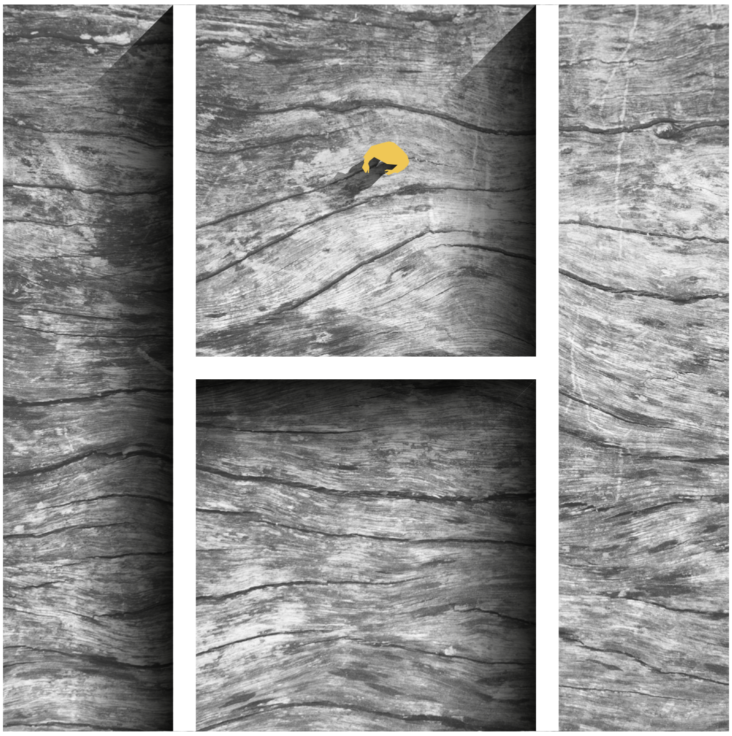
SLAB SYSTEM DEFINITION

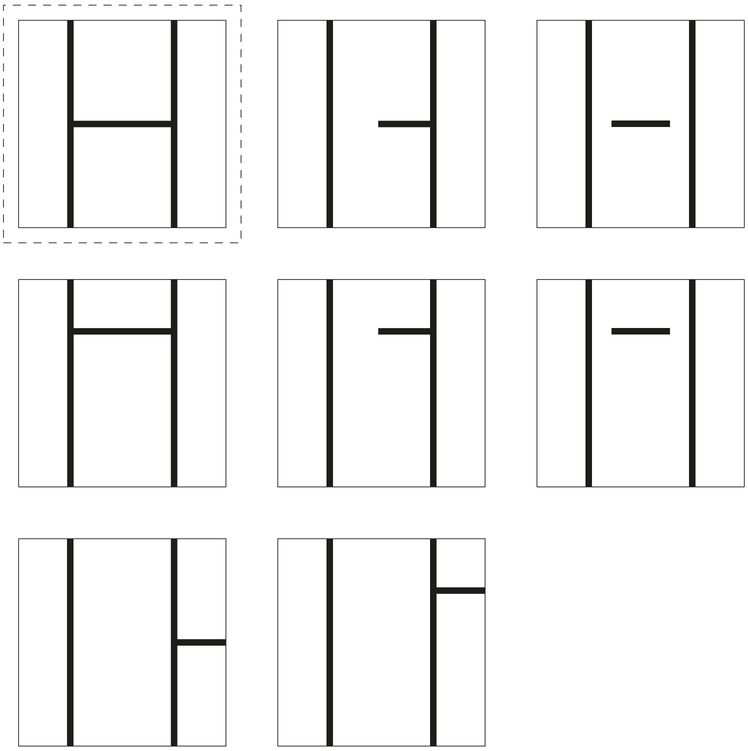
In my explorations regarding configurations, I have used a slab system in which the slabs span 4,8 metres between two load-bearing walls and continues as cantilevers 2,4 metres on each side of these walls. In the drawing, the yellow walls support the slabs, while the green one is added for horizontal stability. This colour-coding is used in all the configurational drawings that follow in this chapter.



STACKED SUPPORTS

In this very basic configuration, the walls that support the slabs are stacked on top of each other. Only the green wall on each floor can be placed freely and make each floor plan unique.



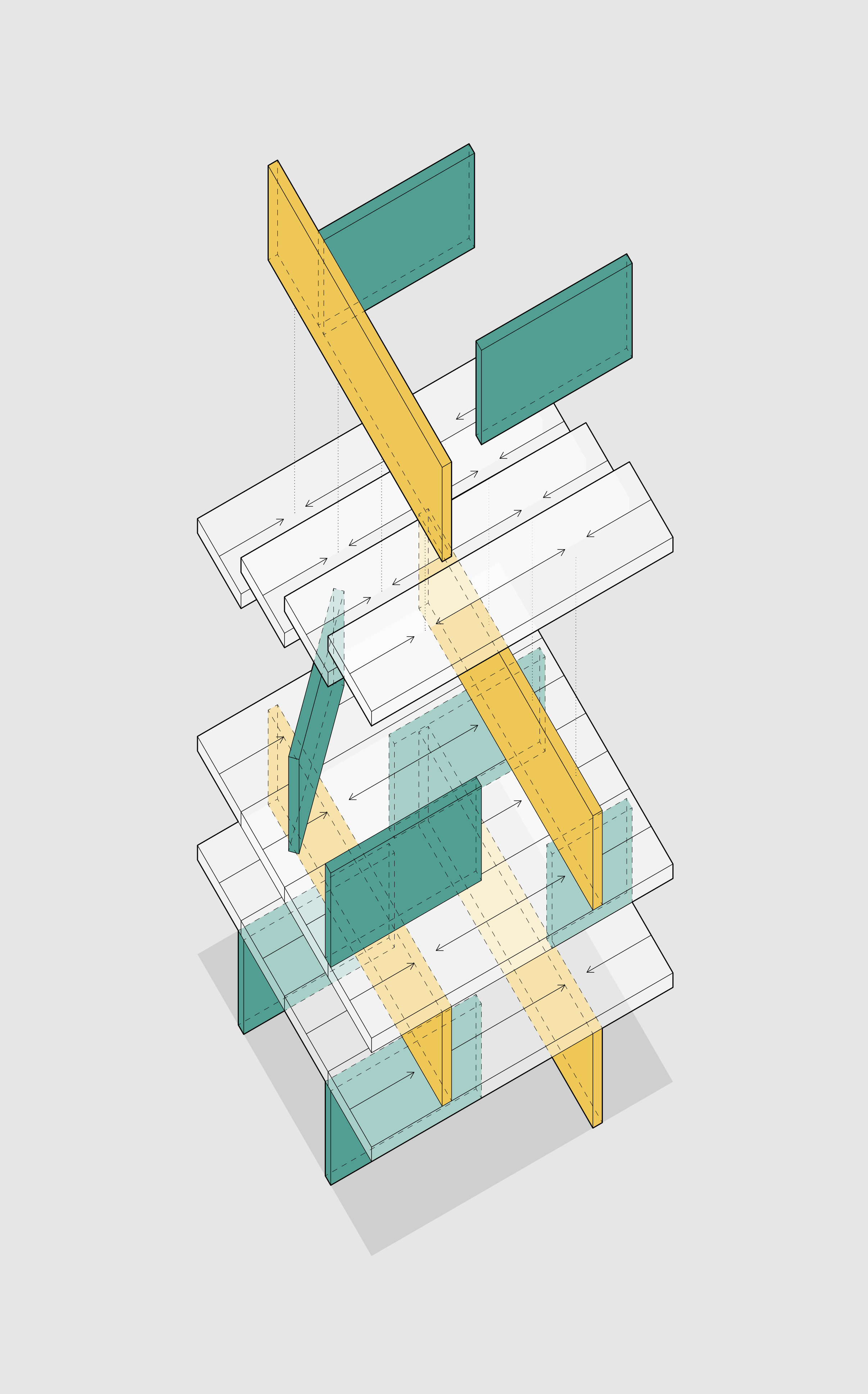



0 1 2 3 4 5 m

THE FULLY SUPPORTIVE PLAN

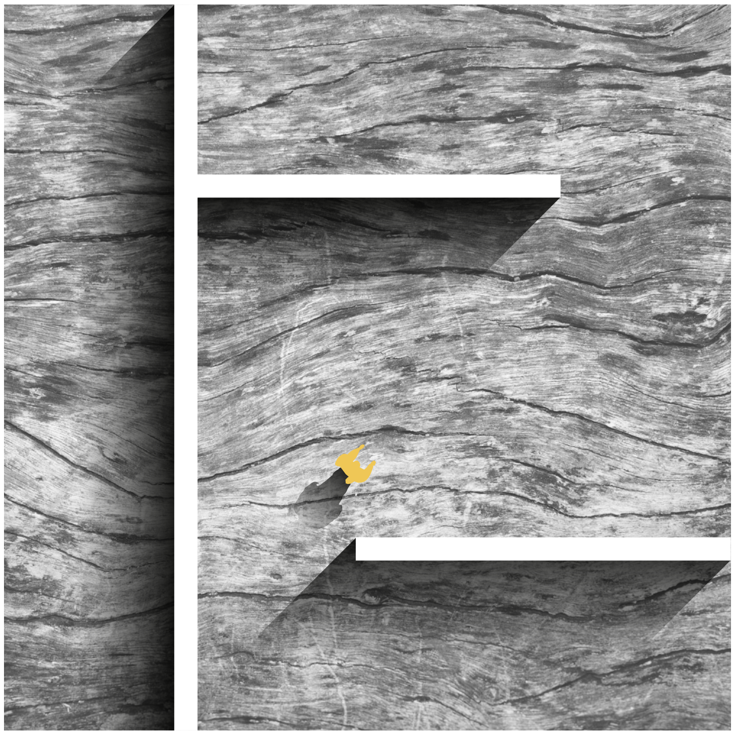
This drawing shows some examples of floor plans that are possible with the *stacked supports* configuration. Characteristic for all of them are the three long spaces, going through the whole floor plan, perpendicular to the span direction of the slabs. By using the additional shear wall to divide one of them, four enclosed spaces can be defined.

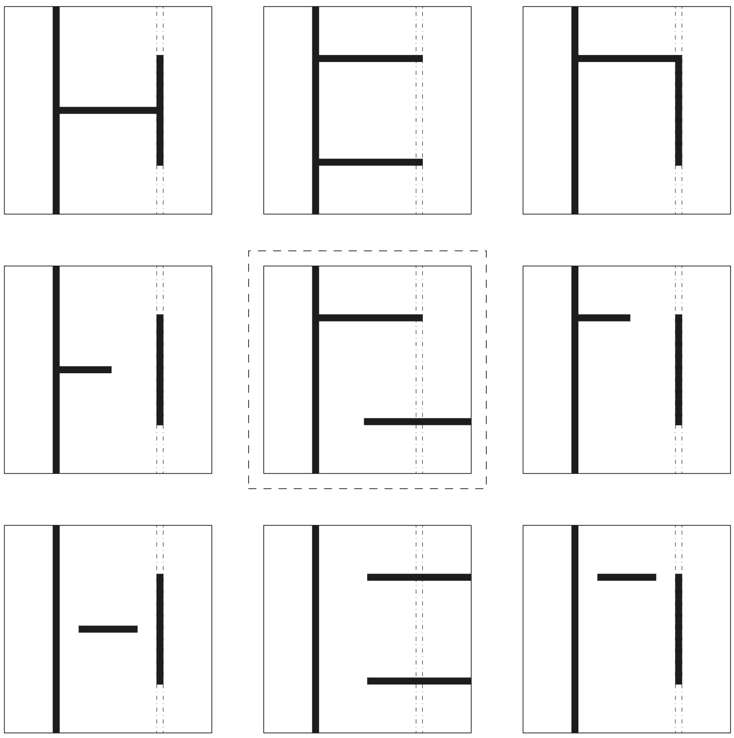
The chosen example is symmetrically divided, which creates two long spaces and two square ones.

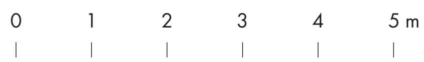


ALTERNATING SUPPORTS

By using the yellow walls as beams and partially suspending the slabs from above, every other of the yellow walls from the *stacked supports* configuration can be removed. By doing this, the two green walls on each floor can be placed freely, as long as they provide horizontal stability and vertical support for the yellow wall above them.



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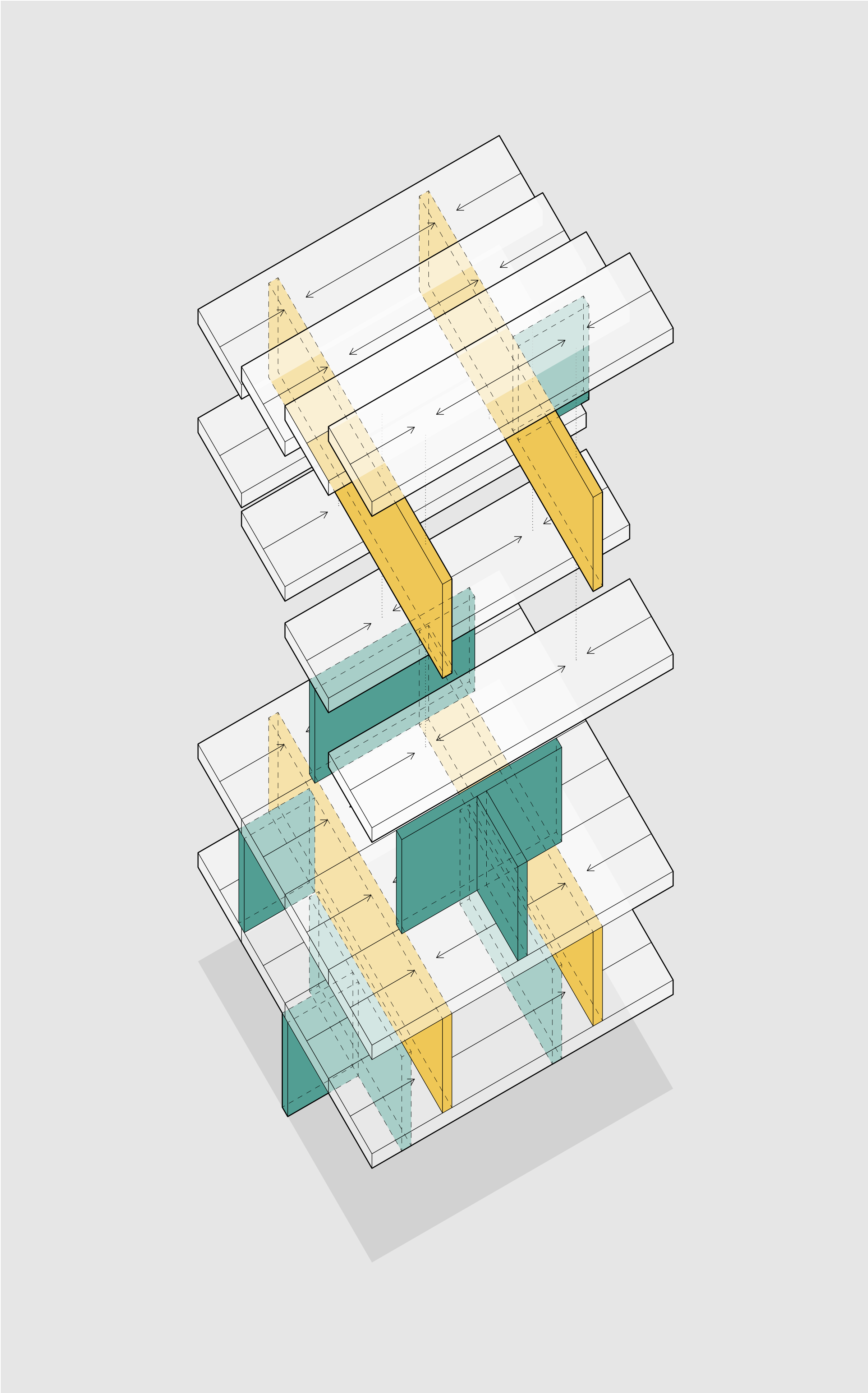
THE HALF-SUPPORTIVE PLAN

When removing one of the walls that support the slabs, a more two-directional floor plan is possible. Circulation between some of the spaces is also made possible, since the two shear walls can be placed in a way so that they leave one or two openings between the spaces they define.

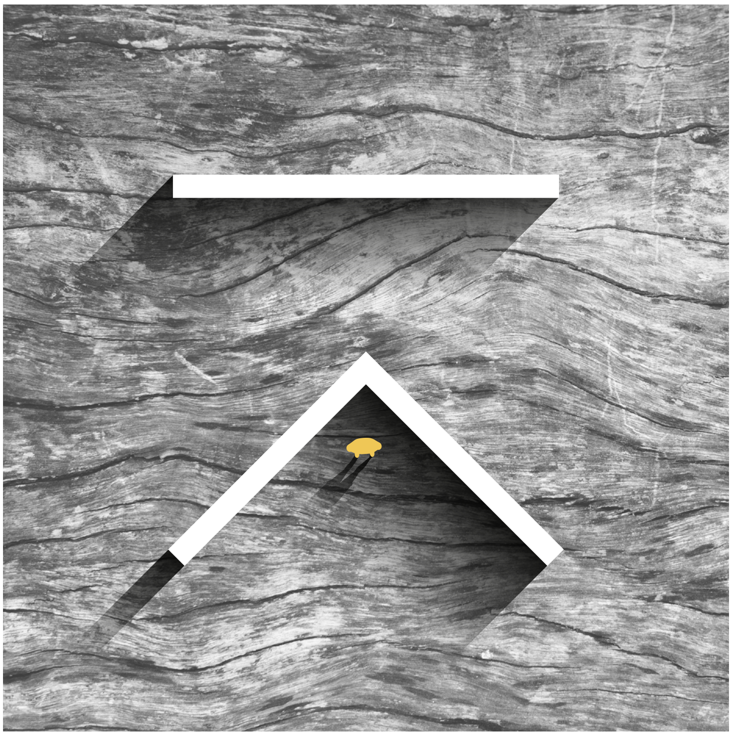
In the chosen example, the walls are placed to create a zig-zag movement between the three connected spaces.

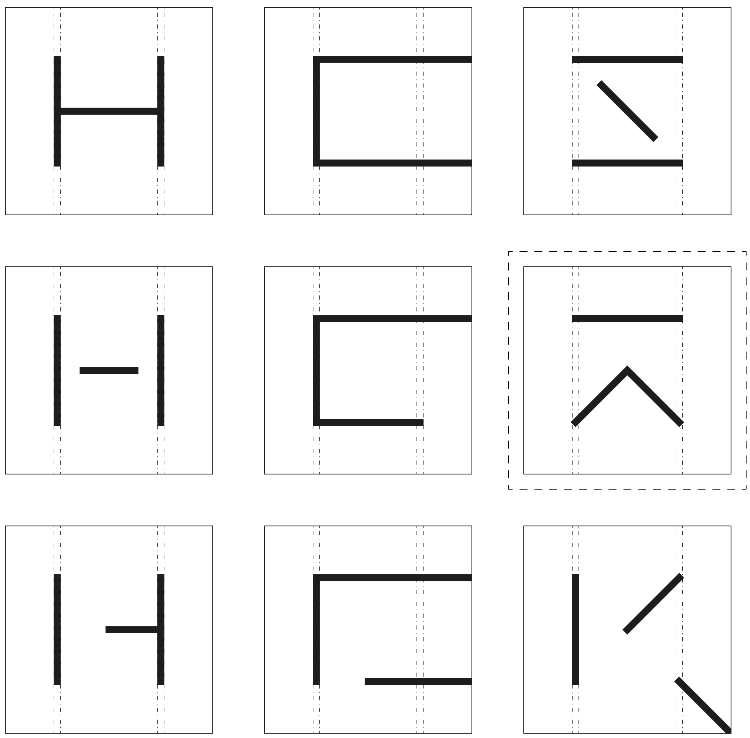


EVERY OTHER STORY

In this configuration, all yellow walls are used as beams holding the slabs both above and below them. This way, all three green walls on the other two stories can be placed freely, as long as they provide horizontal stability and vertical support for the two yellow walls above them.

Especially interesting with this configuration is the mix between open and closed floor plans.



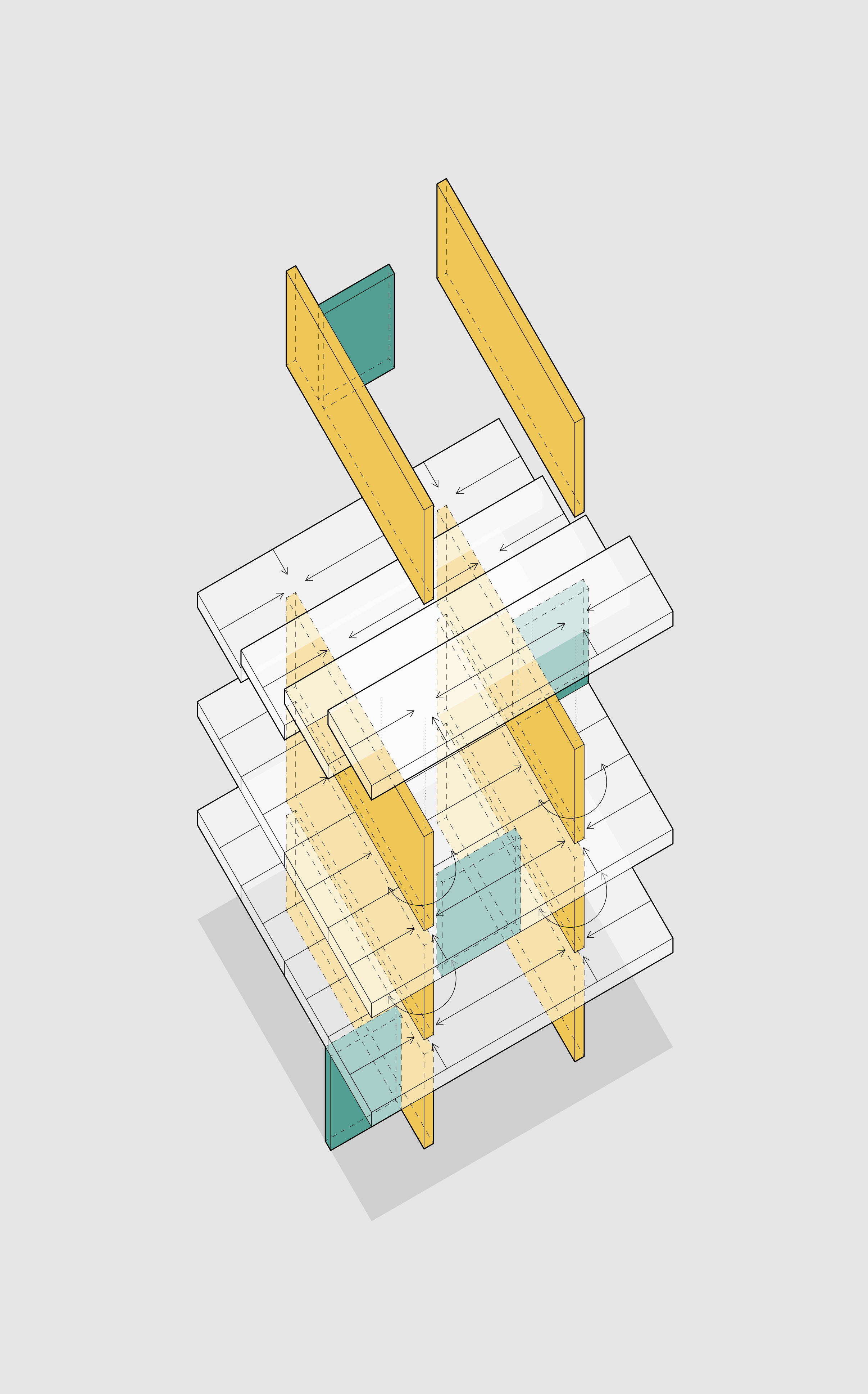



0
1
2
3
4
5 m

THE VERTICALLY SUPPORTIVE PLAN

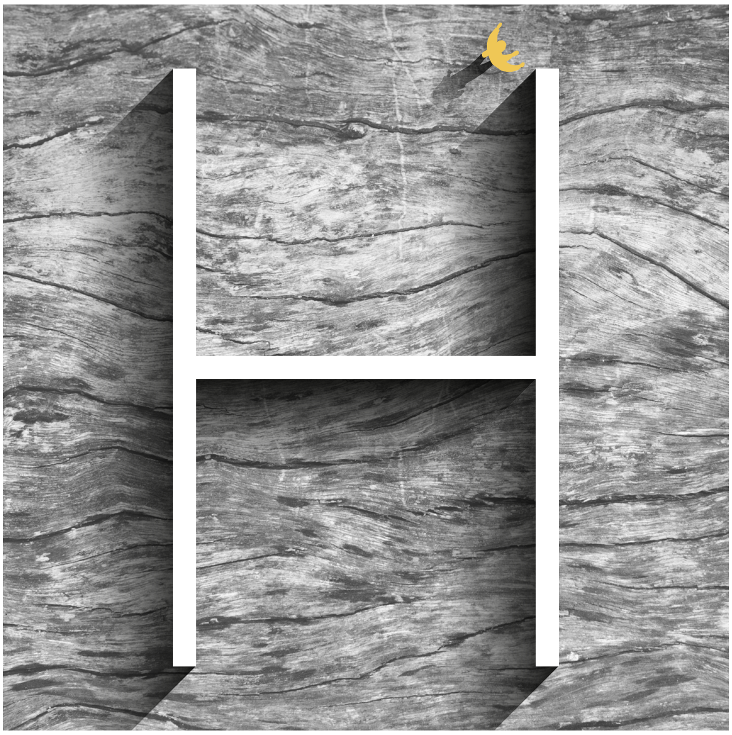
The possibility to place all three walls freely opens up for many different floor plans.

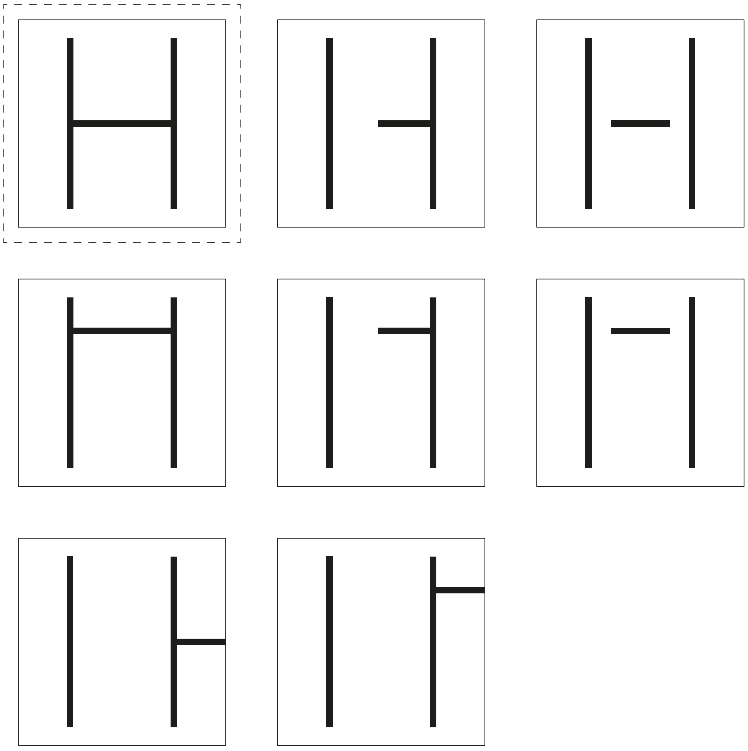
The chosen example is one of my personal favourites. It has no enclosed spaces, which allows for a free movement around the load-bearing walls. However, the two connected walls loosely define a corner space directed out towards the facade and the potentially open view.



RECESSED WALL PASSAGES

This drawing shows a variation of the *stacked supports* configuration where the walls are slightly recessed from the facade, creating a small two-way span in the slab. By doing this, a small passage between the spaces is made possible.



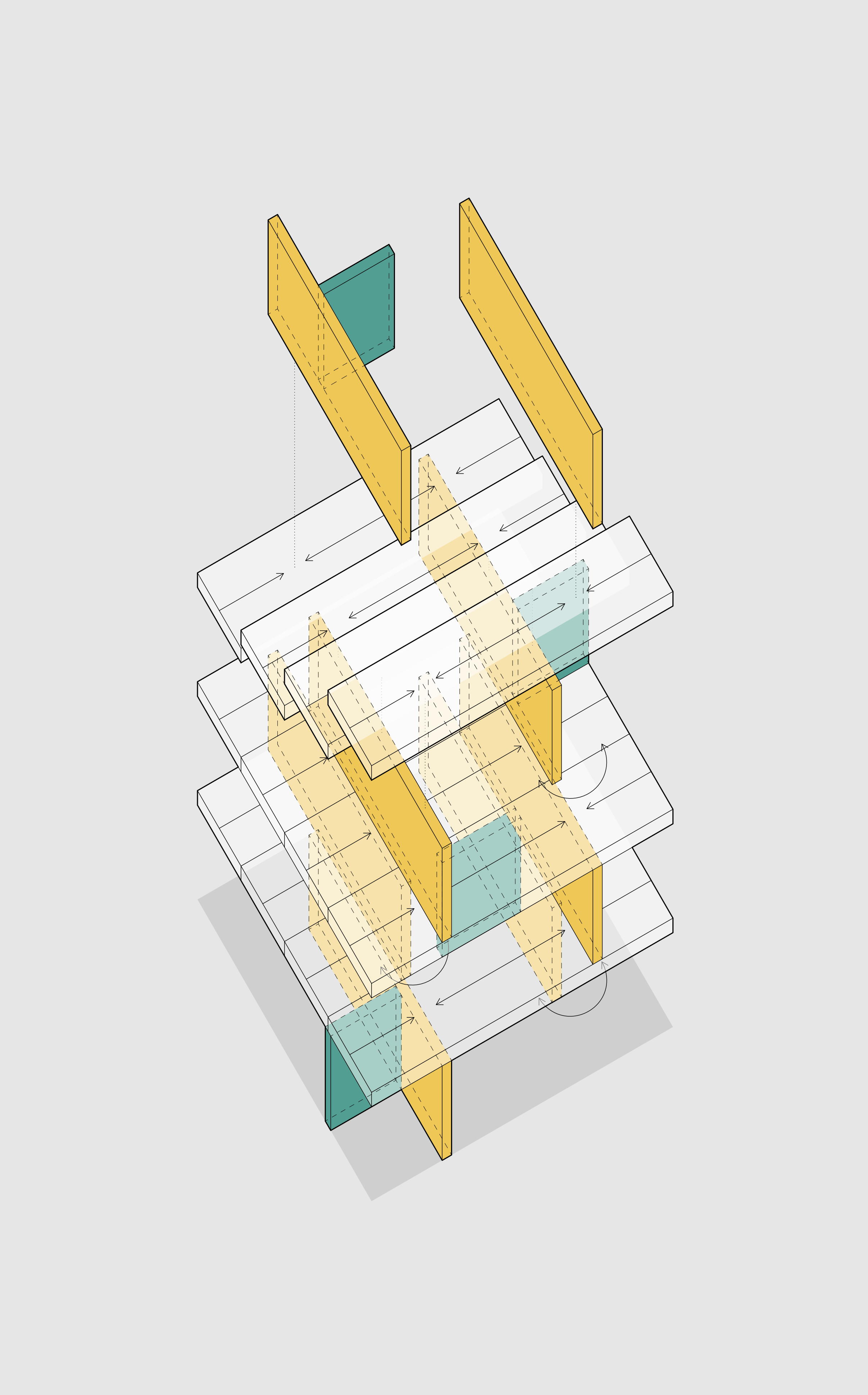


0 1 2 3 4 5 m

THE PLAN WITH RECESSED WALLS

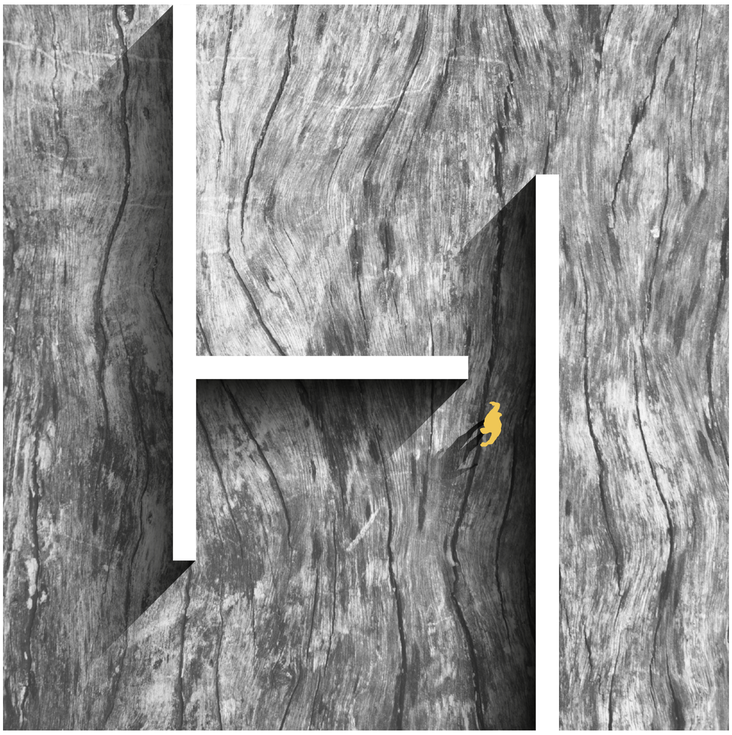
In this kind of floor plan, the circulation between spaces takes place by the facade, which allows the centre of the floor plan to be totally closed.

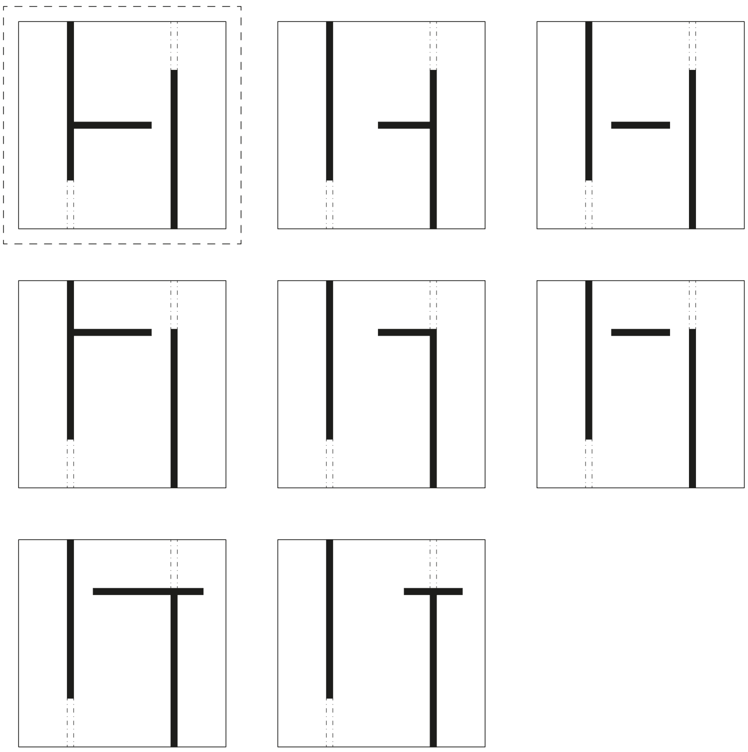
The chosen example features two long spaces defined only by one wall in combination with two more enclosed spaces defined by three walls.



ALTERNATING PASSAGES

In this configuration, the yellow walls are stacked just as in the *stacked supports* configuration, but they are shorter and shift alternately from side to side, which creates two passages on each floor. To make this possible, some slabs are partially suspended from a yellow wall above them. Here, the passages on each floor are placed on opposite sides of the structure, but it would also be possible to have them on the same side, or even place them freely according to the needs of the inhabitants.





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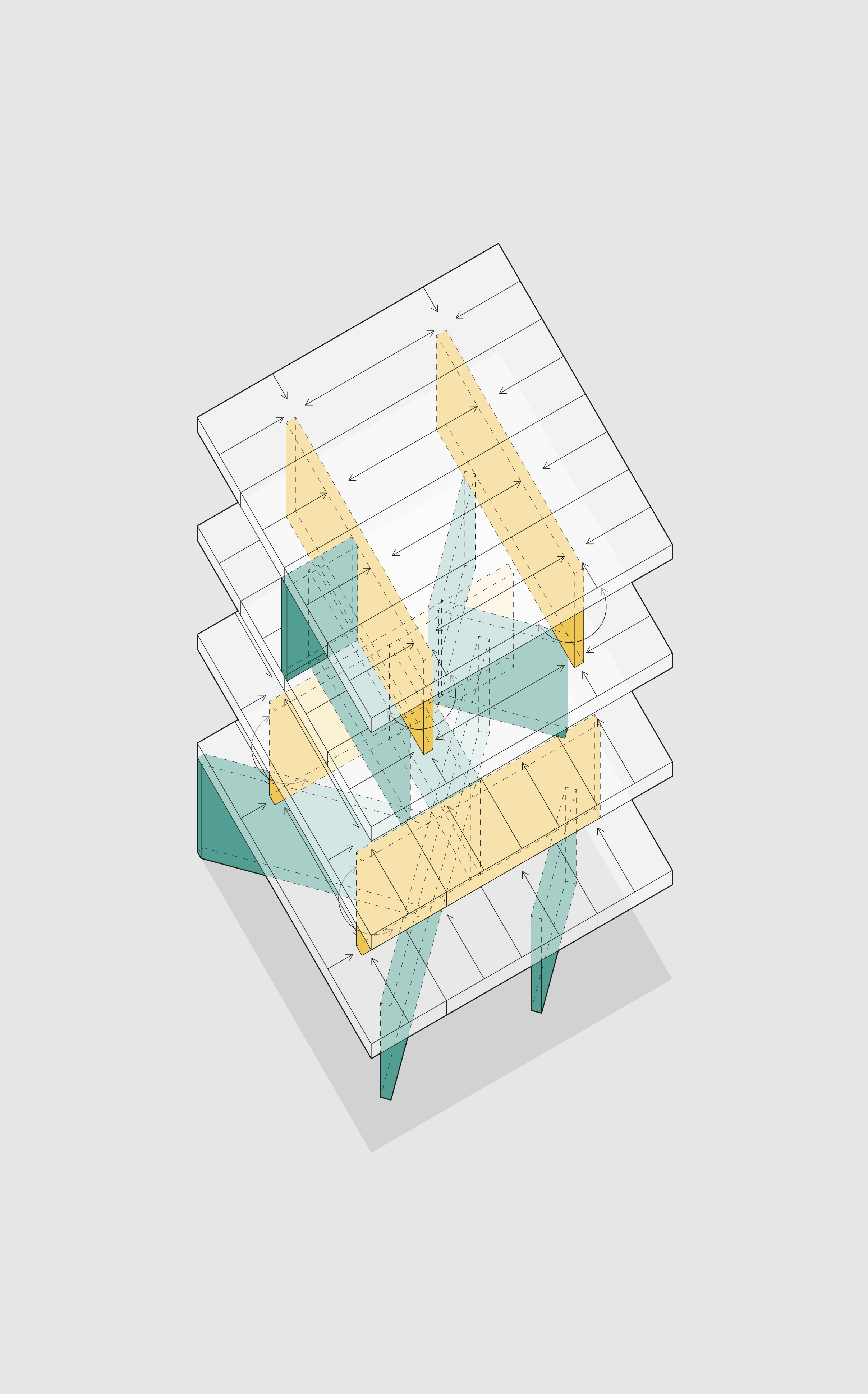
THE ALTERNATING PASSAGES PLAN

This kind of floor plan is organized in a Z-like shape and has two distinguished end points, while the centre of it can be divided in different ways using the shear wall.

The chosen example has a rather closed centre with two defined corner spaces and a small passage between them.



CHOSEN CONFIGURATION

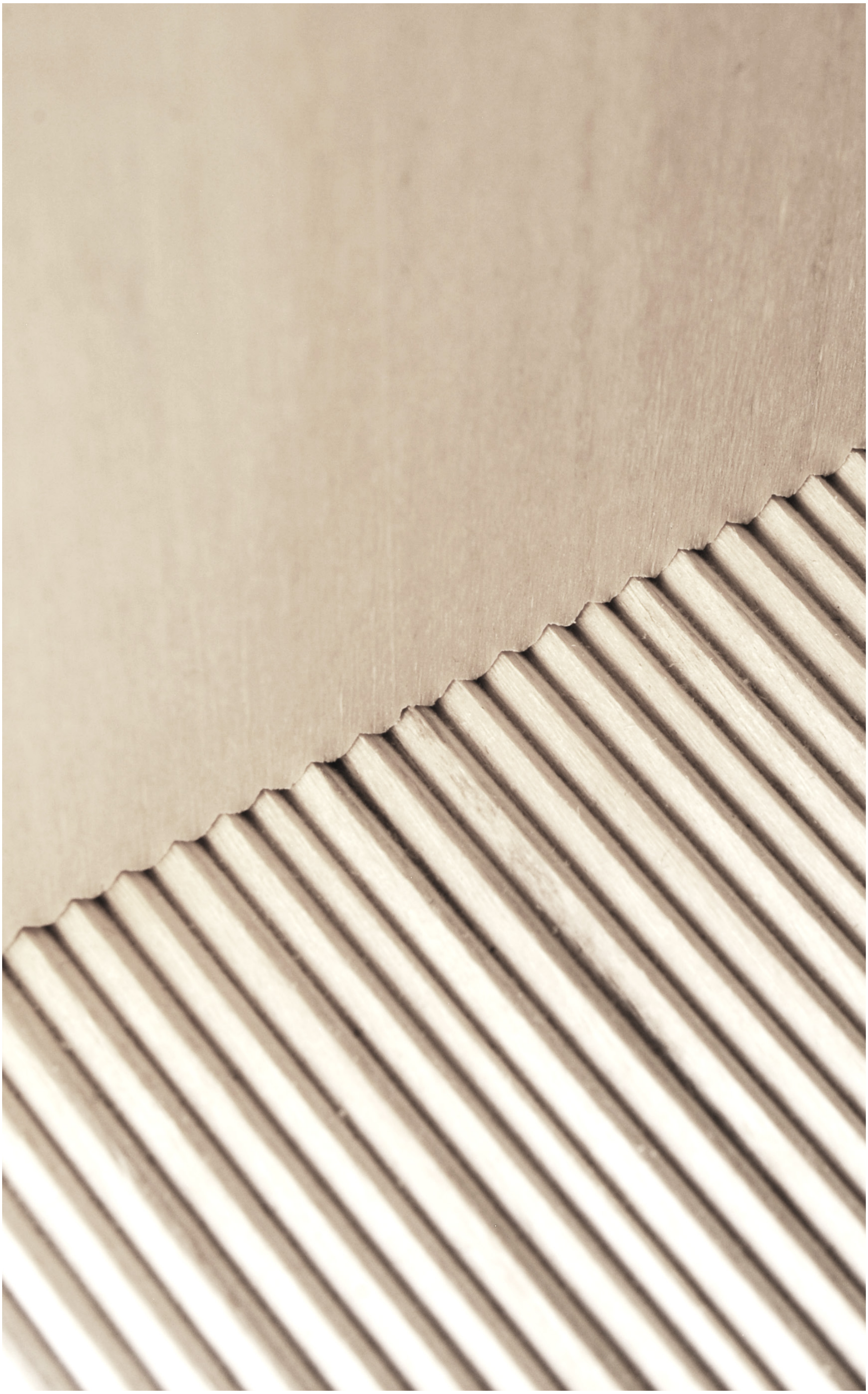
The first iteration of my design can be described as a variation of the *every other story* configuration with recessed walls for circulation. The aim was to achieve a variation of spaces. The first and third floor are two different variations of *the vertically supportive plan*, both featuring diagonal walls. One of them is quite closed and the other very open. The other two floors are (by necessity) different variations of *the fully supportive plan*.

Note that the span direction of the slabs changes halfway through the structure.



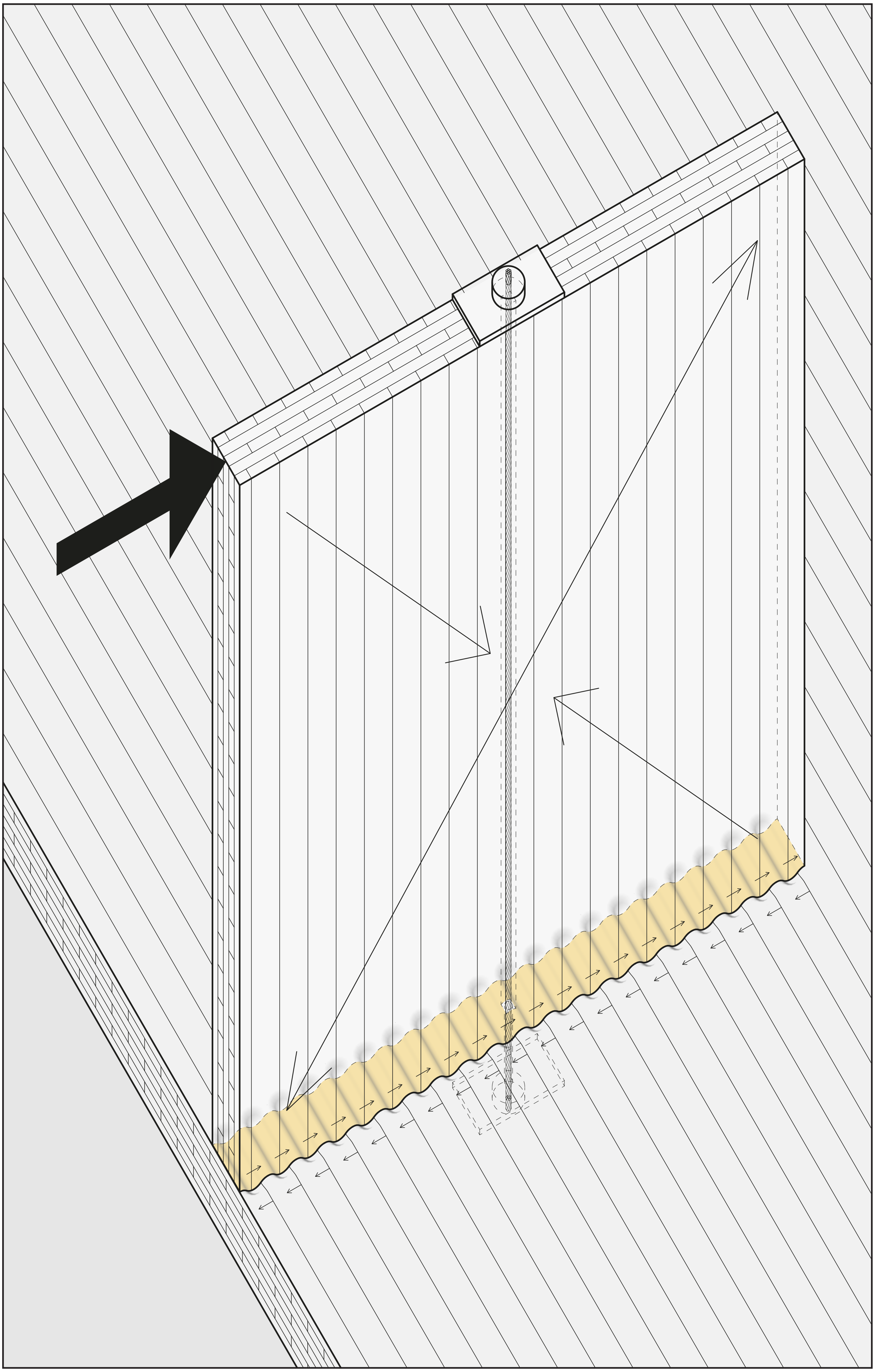

EARLY VISIONS

The images to the left are modified photos of a 1:50 scale model. While providing me with early visions of the spaces defined by the structure, they also helped raise the question of how the structural elements are joined together. Because if they were joined in a conventional way, using screws and brackets, the spaces would not appear as in the photos, but have visible screw heads and steel connectors.



PROTOTYPE OF RIBBED JOINT

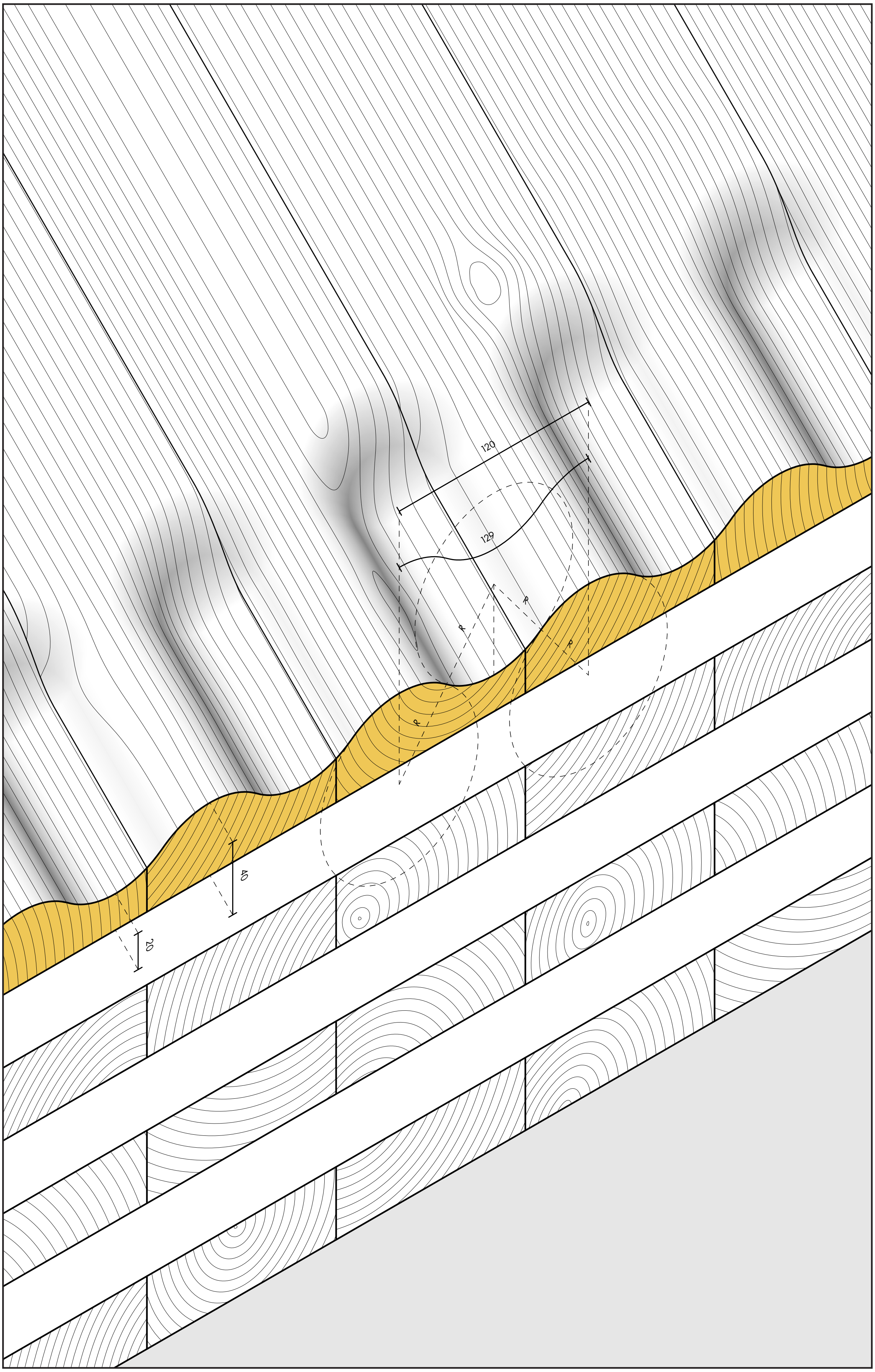
After being asked by my examiner what the corners between walls and slabs will look like, as well as reading some of Christopher Robeller and Yves Weinand's work on CNC-crafted joints between timber plates, I searched for ways to use the shape of the elements to transfer forces between them. This approach is called integral mechanical attachment (Robeller & Weinand, 2016). In this early prototype, a ribbed pattern in the slab matches the edges of a wall, causing them to interlock. This way, horizontal forces can be transferred between walls and slabs.



0 10 20 30 40 50 cm

THE WAVE JOINT

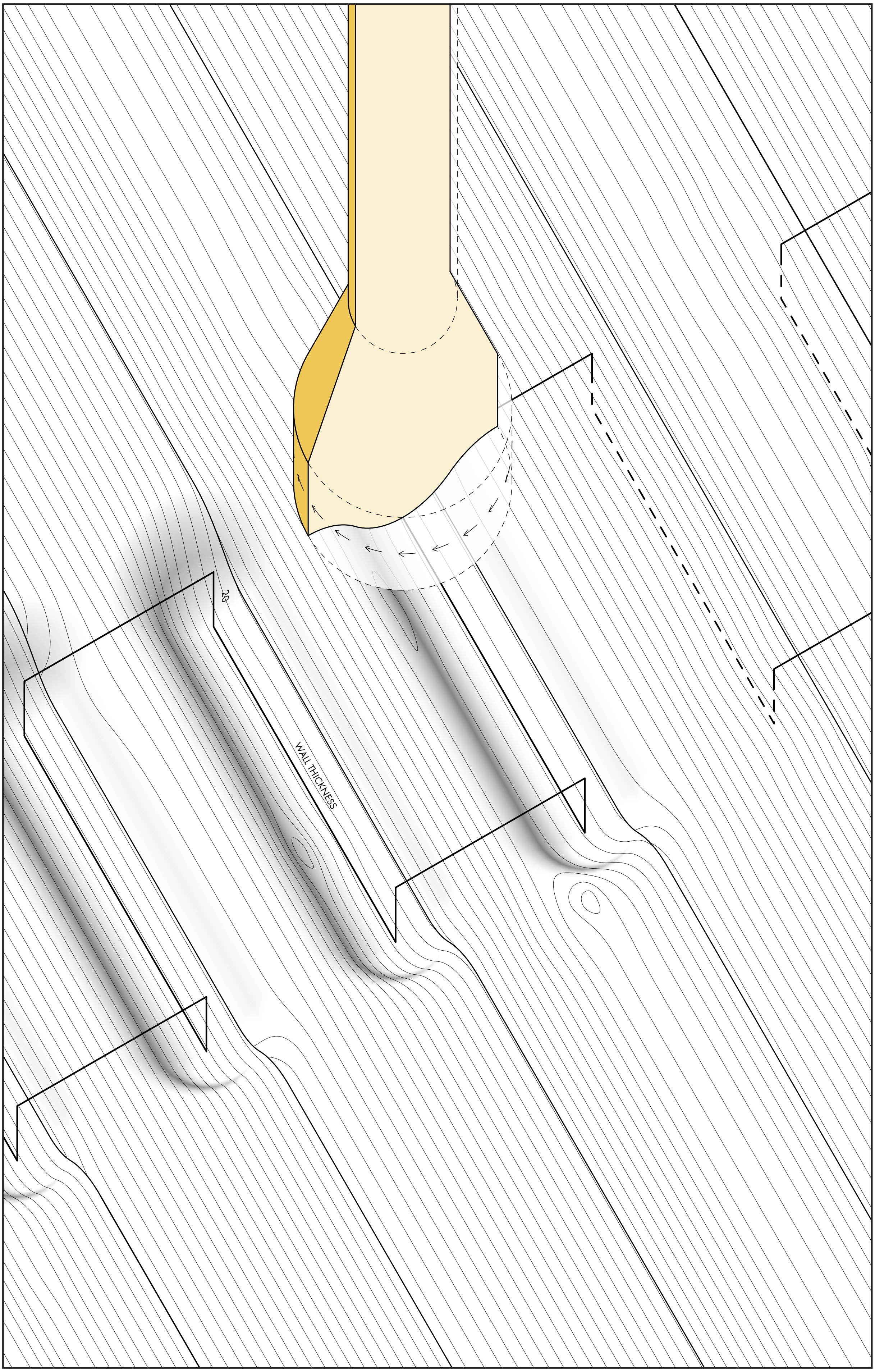
The wave joint is a development of the prototyped ribbed joint and the result of my explorations on how to transfer horizontal loads between walls and slabs using integral mechanical attachment. The aim has been to design a structural joint that is also an architectural detail. Through the wave-shape, loads are distributed evenly across the area of contact, causing minimal stress concentration. Since the gravitational force pushing them together is probably not large enough, a post-tensioned wire is added to pull them together. When assembled, the joint displays a wave-like shape in the corner between the wall and the slab that resembles a seam. This gives the inhabitants a hint of how the structure is put together.



0 1 2 3 4 5 6 7 8 9 10 cm

SECTION OF WAVE

The wave pattern in the slab is designed to leave most of the top layer of the slab intact, allowing for it to pass more or less continuously through the joint without losing much of its structural capacity.



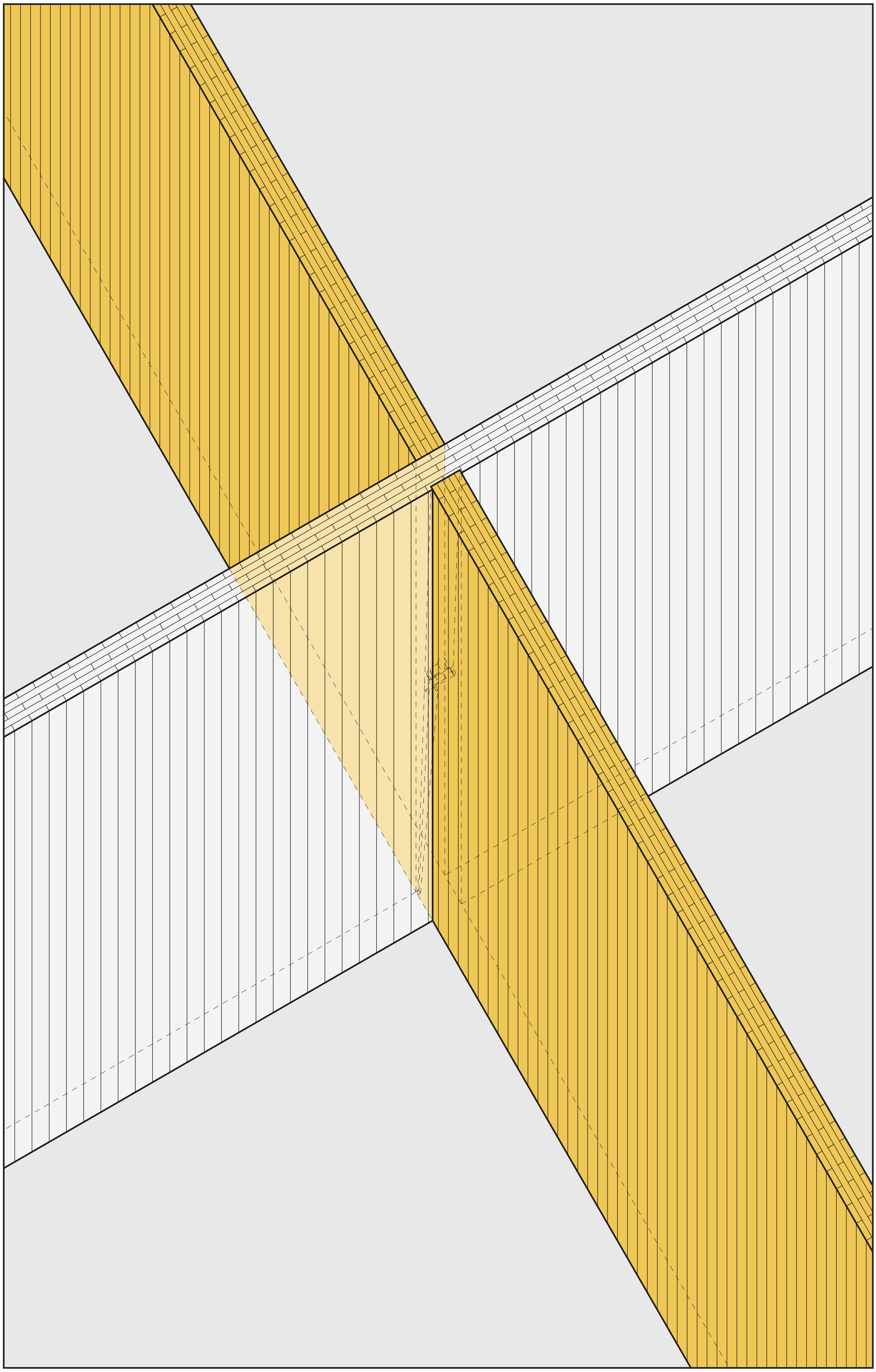
0 1 2 3 4 5 6 7 8 9 10 cm

CNC-CRAFTING OF WAVE

By using a CNC machine and a custom drill bit with a wave-shaped profile, the wave-shape can be carved into the slab. By changing the length of the carvings, different wall thicknesses can be used.

PROTOTYPE OF CROSS JOINT

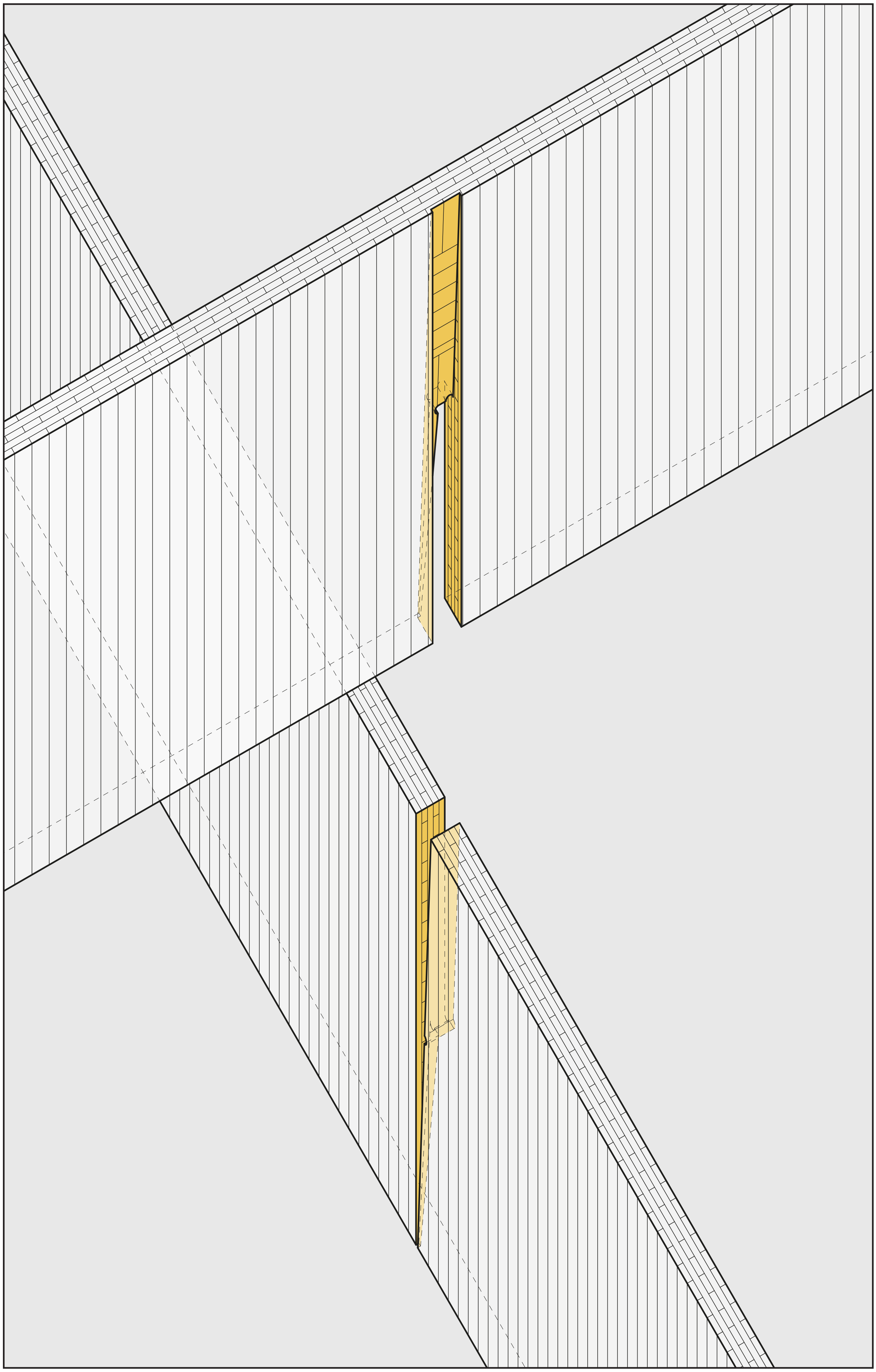
The idea of crossing walls had been in my mind for some time. After some time in a digital model, trying to figure out how to make the joint wedge-shaped and how to make it as tight as possible by recessing the walls into one another, I went down to the workshop and made this prototype. As seen in the photo, some of the interior surfaces are slanting, which causes a fit that gets tighter the further the two parts are assembled. When in place, the two parts are totally interlocked.



0 50 cm

THE CROSS JOINT

This drawing shows a refined version of the prototyped cross joint. It is designed to be pre-fabricated and assembled without using any screws or other steel fasteners. Since the walls pass more or less continuously through the joint, it is possible to create more divisions using only three walls, since each wall can cross one or two others. By letting one or both of the walls end just after they have passed through the joint, connections quite similar to those used in log houses can be achieved, where the elements display their end grain.



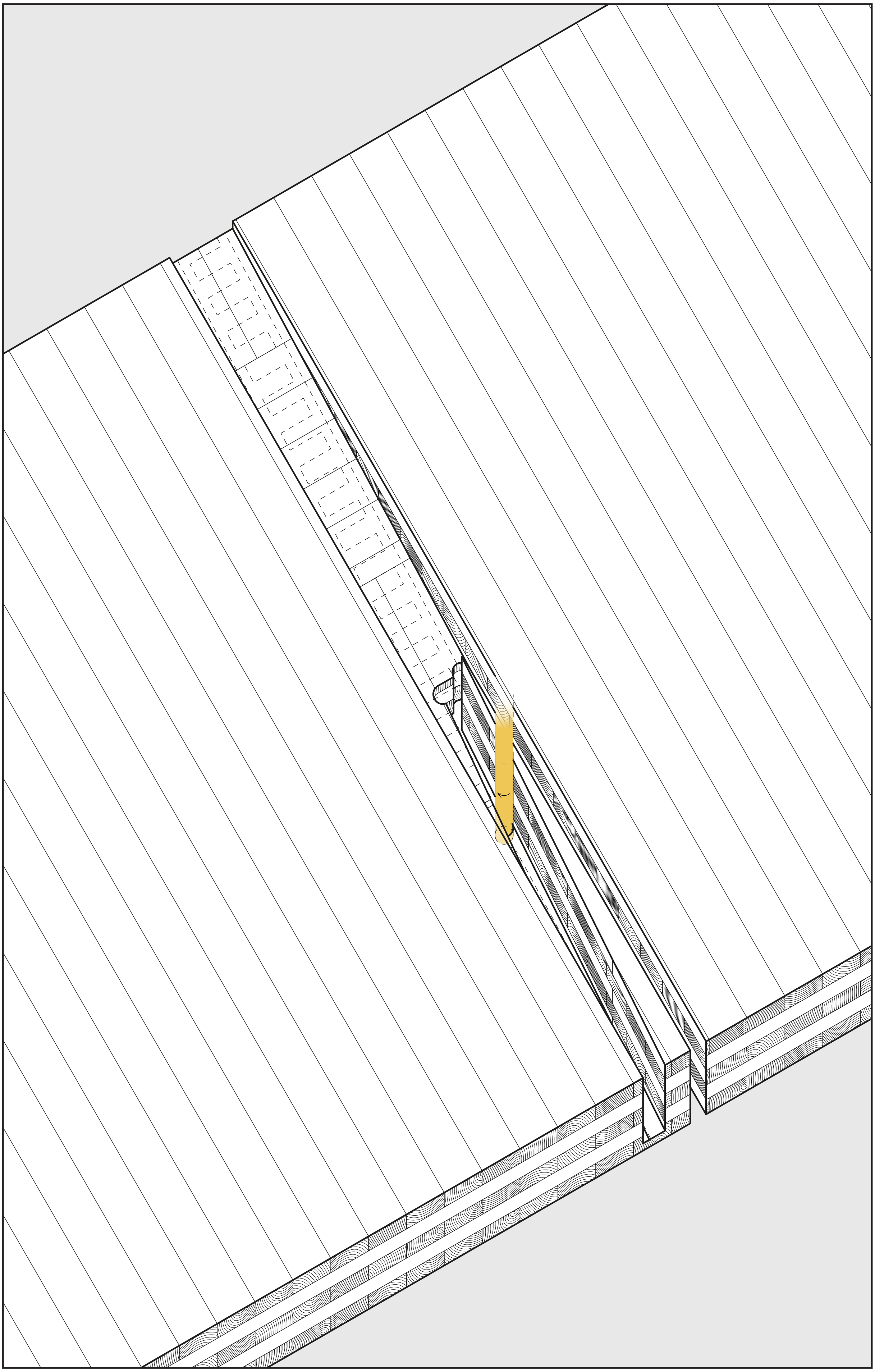
0 50 cm

EXPLODED CROSS JOINT

The cross joint is wedge-shaped to facilitate an easy assembly, while still attaining a tight fit when in place.

By recessing each wall into the other, a more closed joint is achieved, where one wall in most cases appear to pass through the other.

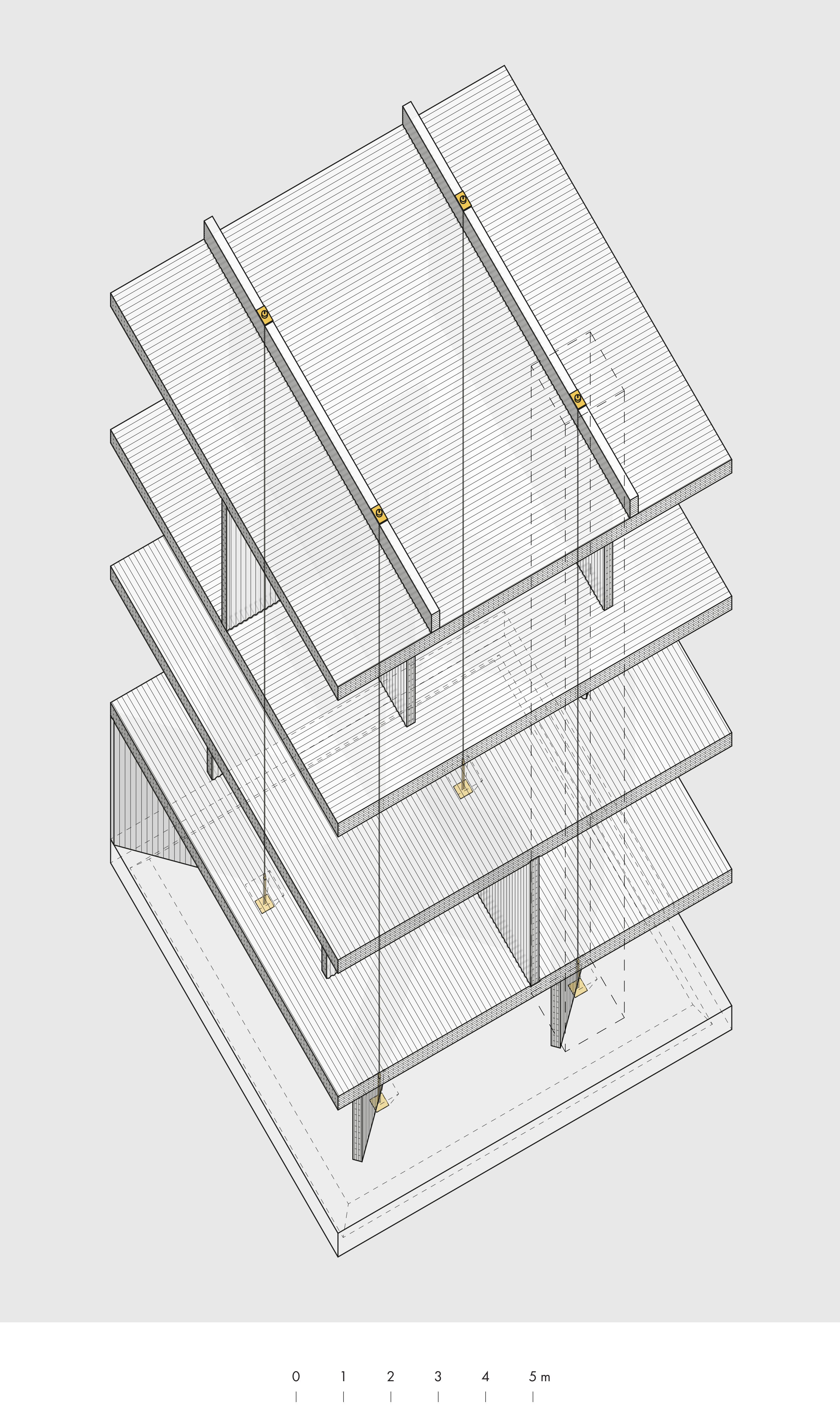
Note the circular notches in the interior corners. They are sometimes called Mickey Mouse Ears and are added because a CNC-cutter with a rotating drill bit cannot cut sharp corners (Robeller & Weinand, 2016). In this joint, they are placed in a way so that they are hidden when the joint is assembled.



0 10 20 30 40 50 cm

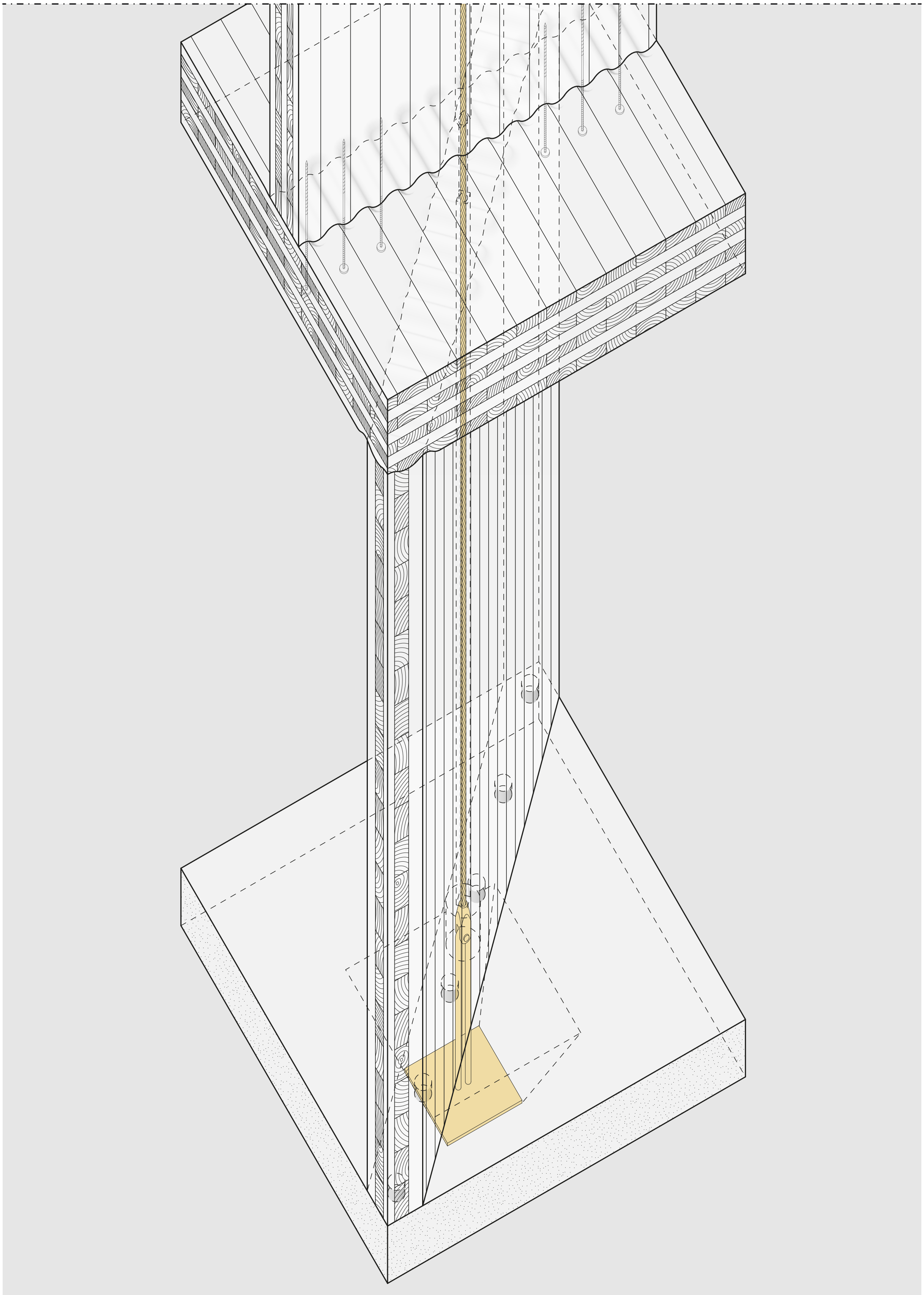
CNC-CRAFTING OF CROSS JOINT

The two different parts of this joint are designed to be carved out of the wall panels when lying down on one side, without having to turn them over. To achieve the slanting surfaces that make the joint wedge-shaped, a 4-axis CNC machine is required.


0
1
2
3
4
5 m

PROPOSED STRUCTURE

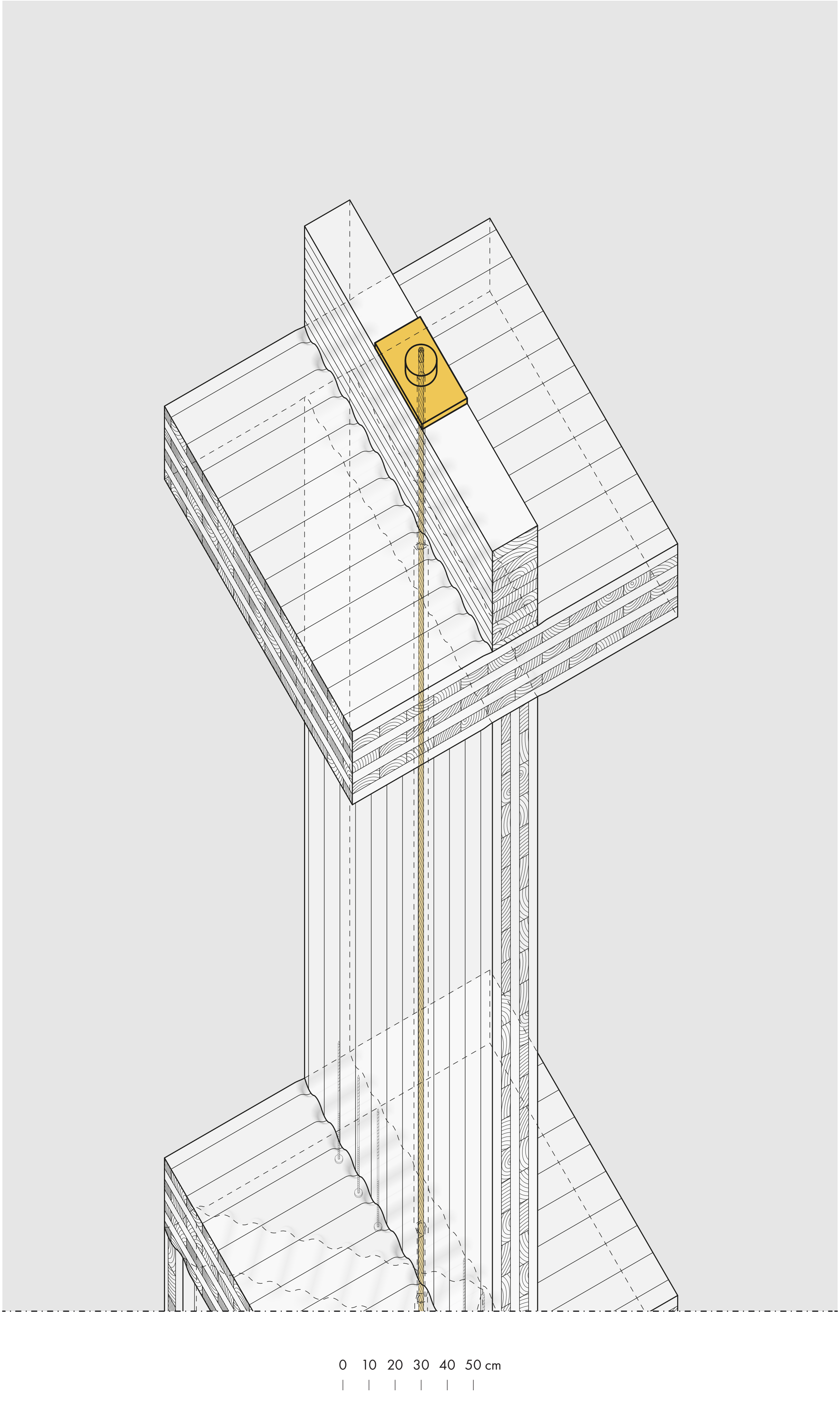
In the second iteration of my design, the developed joints are implemented. Here, every wall is either freestanding or crossing one or two other walls. The wave joint is used in every meeting between walls and slabs. Four post-tensioned steel cables hold the structure together and by attaching them to cast-in anchors in the foundation they also fix the building to the ground. At the top, glue-laminated beams, also featuring the wave joint, are added to distribute the pressure caused by the post-tensioning more evenly.



0 10 20 30 40 50 cm

ANCHOR

This drawing shows a vertical cut around one of the cables. Here, you can see how each cable is attached to an anchor that is cast into the concrete foundation. This way, the cable not only holds the structural elements together, but also fixes the structure to the ground.


0 10 20 30 40 50 cm

TOP SCREW

When the structure is assembled, the cables that go through it are attached to screws at the top and post-tensioned to ensure that the structural elements are held tightly together. This causes the wave joints to interlock, which in turn makes the structure stable.

VISIONS OF A *SOLID PLAN*

The images here, on the last pages of my booklet, are my conclusion. They are based on photos of a 1:20 scale model of the third floor of the proposed structure. The model features the actual joints that have been developed and, in the photos, you can see how they manifest themselves in space. With a little imagination, hopefully, they can give a hint of a new kind of wooden architecture; one that utilizes modern technique, while still sharing DNA with the very roots of wooden architecture, the log house.

I give you the *solid plan*.

REFERENCES

WRITTEN

Falk, A. (2005). *Architectural Aspects of Massive Timber*. Luleå, Sweden: Luleå University of Technology

Merleau-Ponty. (2008). *The World of Perception*. (O. Davis, Trans.) Abingdon, England: Routledge

von Moos, S. (1979). *Le Corbusier - Elements of a Synthesis*. Cambridge, Massachusetts, and London, England: MIT Press

Robeller, C., Weinand, Y. (2016). *A 3D Cutting Method for Integral 1DOF Multiple-Tab-and-Slot joints for Timber Plates*. Vienna, Austria: 2016 World Conference on Timber Engineering

VIDEO

Harvard Graduate School of Design [Harvard GSD]. (2012, September 12). *The Rule of the Game - Christian Kerez, 2012 Kenzo Tange Lecture* [Video file]. Retrieved from https://www.youtube.com/watch?v=srONiu7ExHo